Ecological Research Associates

BEHAVIOR, DISTURBANCE RESPONSES AND DISTRIBUTION OF BOWHEAD WHALES *Balaena mysticetus* IN THE EASTERN BEAUFORT SEA, 1982

by

LGL Ecological Research Associates, Inc.
1410 Cavitt Street
Bryan, Texas 77801

for

U.S. Minerals Management Service
12203 Sunrise Valley Dr.
Reston, VA 22091

November 1983

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PROJECT RATIONALE, DESIGN AND SUMMARY, 1982*

By

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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. The Western Arctic stock now contains more bowheads than the others, but even it is considered endangered. The International Whaling Commission's current 'best estimate' of the population size is 3857 (I.W.C. 1983).

The Western Arctic bowheads winter in the Bering Sea and summer in the eastern Beaufort Sea (Fig. 1). Their spring and autumn migrations are around the western and northern coasts of Alaska. The spring migration is close to shore in the Chukchi Sea, but well offshore in the Alaskan Beaufort Sea (Braham et al. 1980; Ljungblad et al. 1982a). Thus, the eastward spring migration through the Alaskan Beaufort Sea is well north of the area of imminent oil exploration near the coast. However, during the westward autumn migration many bowheads occur close to the Alaskan north coast and within or near some offshore oil leases (Ljungblad et al. 1982a).

Bowheads move eastward through the Alaskan Beaufort Sea from April to early June and return westward through that area in September and October. From May to September, the great majority of the population is in Canadian waters (Fraker 1979; Fraker and Bockstoce 1980; Davis et al. 1982). Intensive offshore oil exploration 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 that area (Richardson et al. 1983a)

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, but there have been few detailed or controlled studies of these reactions. Long-term effects are less well understood. The

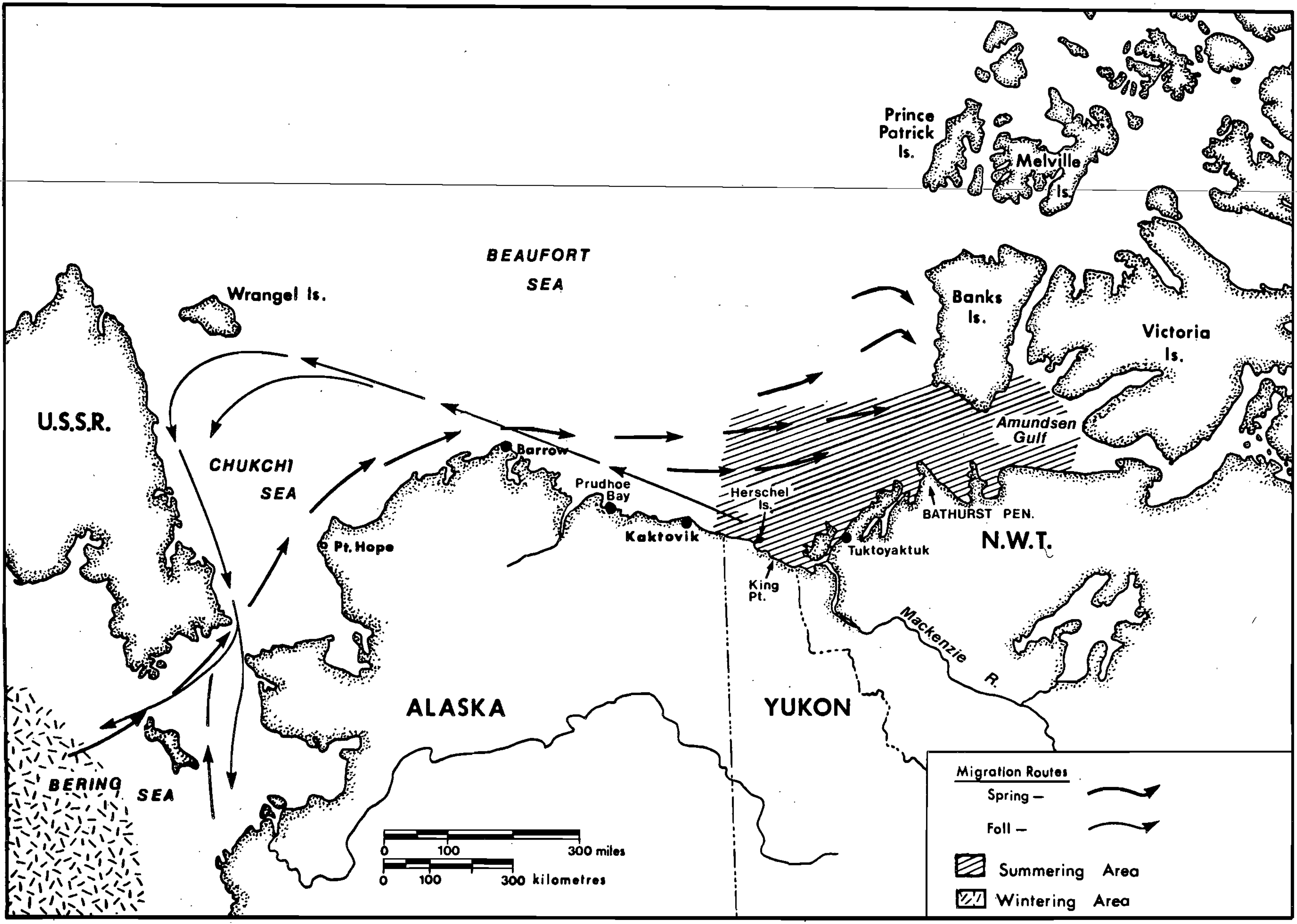

Figure 1. Generalized pattern of seasonal movement of the western Arctic population of bowhead whales.

literature on these topics has been reviewed recently by Fraker and Richardson (1980), Geraci and St. Aubin (1980), Acoustical Society of America (1981), Fraker et al. (1982), Gales (1982), and Richardson et al. (1983b).

Noise is one attribute of offshore oil exploration and development that may have a deleterious effect on marine mammals. 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; Richardson et al. 1983b). Many of the sounds produced are of rather low frequencies, in the order of tens and hundreds of Hertz. This is the frequency range of most bowhead calls (Ljungblad et al. 1982b; Würsig et al. 1982), and it is assumed that bowheads and other baleen whales can detect low frequency sounds.

Sound, unlike light, can propagate long distances through water. With calm to moderate sea states, noise from boats, dredging and drilling is readily detectable by instruments, and presumably by bowheads, at ranges of several kilometres or more (Greene 1982). 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). 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 wherein a bowhead could detect industrial noise, there is the potential for disturbance. This could take the form of disruption of normal behavior, displacement, or interference with detection of natural sounds.

The possible negative effects of any prolonged displacement or disruption of normal behavior have been discussed at length in the reviews cited above, but interference with detection of natural sounds warrants further comment. Detection of environmental sounds, such as those from ice, may be important to bowheads. In addition, bowheads themselves produce a variety of types of calls (Ljungblad et al. 1982b; Würsig et al. 1982; Clark and Johnson in prep.). There is little direct information about the functions and importance of these calls. However, analogies with the better-studied and closely related southern right whale, Eubalaena australis, suggest that some call types are used to maintain contact, and others serve communication functions during social interactions (Würsig et al. 1982; cf. Clark 1982, in press). The importance of these forms of communication is difficult to judge, but prolonged disruption of acoustic communication could have significant negative effects. Such disruption could occur either if bowheads for some reason ceased calling in the presence of industrial activity, or if their calls were masked by industrial noise. Increased noise levels reduce the signal (i.e. bowhead call) to noise ratio at any range from the calling animal, and therefore--if other factors are unchanged--will reduce the range to which another bowhead could hear the calling one. The significance of a reduced range of potential communication is unknown, although one can imagine circumstances where long-range acoustic communication could be important (e.g., in locating small areas of open water within heavy pack ice during spring migration).

APPROACH IN THIS STUDY

This report includes our results from 1982, the third year of a study of the normal behavior and disturbance responses of summering bowhead whales. Tasks addressed in 1980-81 included field studies of (1) normal behavior, (2) reactions to industrial activities, and (3) characteristics of feeding areas (Richardson [ed.] 1982).

Task (1), the study of normal behavior, was done because an understanding of the activities of bowheads in the absence of disturbance is necessary in order to interpret their behavior in the presence of industrial activities. There had been no previous study of the behavior of summering bowheads, and little previous study of behavior at any season. Considerable information about normal behavior was obtained in 1980-81 (Würsig et al. 1982).

Task (2) included work on reactions of bowheads to boats, aircraft, seismic exploration, dredging and drillships (Fraker et al. 1982). Both observational and experimental work were included. The experimental work in 1980-81 included comparisons of behavior before and during

- close approach by boats,
- low altitude overflights by aircraft, and
- firing of an airgun.

The non-experimental work in 1980-81 included observations of bowheads near boats, a seismic vessel, drillships and an island construction operation. Characteristics of the underwater sounds from these industrial activities were also analyzed (Greene 1982).

Task (3), concerning the characteristics of the water mass and of the zooplankton in areas with and without bowheads, was performed to determine whether areas where bowheads occur are unusual in these respects. We found that bowheads tended to occur in areas with higher than average abundance of copepods (Griffiths and Buchanan 1982).

The fieldwork in 1982 was a continuation of tasks (1) and (2). Priority was to be placed on disturbance experiments involving noise from drilling, helicopters, dredging and seismic exploration. In practice, it was possible to conduct drilling noise playback experiments, aircraft overflights at different altitudes, and one boat disturbance trial. We were also able to observe bowhead behavior near drillships and in the presence of seismic noise. Characteristics of the industrial noises to which bowheads were exposed in 1982 were analyzed. Studies of normal behavior were assigned low priority in 1982, but considerable additional information was obtained because such observations are often possible when circumstances do not permit studies of reactions to industrial activities. No further work relating to task (3) was planned or done in 1982.

The general approach in 1982 was similar to that in 1980-81, with emphasis on methods that had proven most successful in earlier years. Whenever possible, we attempted to conduct controlled experiments to test the reactions of whales to industrial activities. The best way to determine the response of bowheads to a source of potential disturbance is by comparing the behavior of a specific group of whales before and during exposure. This experimental method is much more sensitive than uncontrolled observations of some whales in the presence of the industrial activity and others in its absence. Many factors may differ between groups of whales observed at different places and times.

The study area in 1982 was the same as in 1980-81: the southeastern Beaufort Sea, including the area of offshore oil exploration and surrounding areas to the west, north and east. This area was chosen because, relative to Alaskan waters, bowheads are present for a comparatively long period, and weather, light and ice conditions are more favorable. Also, the presence of extensive offshore oil exploration provides certain opportunities for observation that do not now exist in the Alaskan Beaufort Sea. The work was again based at Tuktoyaktuk, N.W.T. Work in 1982 extended west of Herschel Island and east of Cape Bathurst, and as far as 200 km offshore (Fig. 1).

The field season in 1982 extended from 1 to 31 August. The logistic support consisted of the same Islander observation aircraft as used in 1980-81, and the same 13-m boat (MV 'Sequel') as used in 1981. No shore-based observations were attempted in 1982 because of the limited success of shore-based work in 1980-81. Bowheads did not approach close enough to shore in 1980-81 to make shore-based disturbance experiments practical. Given the observed distribution of whales in 1982, it is doubtful that shore-based observers would have had any greater success that year. Many whales occurred in the Herschel Island area, but most were over 5 km from shore (Richardson et al. 1983a).

An additional task for 1982 was to analyze the distribution of summering bowheads during 1980-82 in relation to industrial activities in that period. (Systematic distributional information was not obtained from most parts of the summer range in years before 1980.) The intent was to assess whether there was any 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. However, this preliminary analysis would draw together the information, much unpublished, that would be needed for any future analysis.

No systematic surveys of bowhead distribution were funded under this project. However, separate distributional studies have been conducted in the eastern Beaufort Sea each year since 1980. Additional distributional information, much of it previously unreported, was available from this and other projects dealing with non-distributional topics.

SUMMARY OF RESULTS

This section summarizes the results of the four self-contained sections of the report that follow. These summaries are amended versions of the Abstracts from the four detailed sections.

Normal Behavior of Bowheads, 1982

The report with the above title (Würsig, Clark, Dorsey, Richardson and Wells 1983) describes the 'undisturbed' behavior of bowhead whales summering in the southeastern Beaufort Sea. The emphasis is on the 1982 results, but the report contains considerable integration of results from 1980-82.

Behavior of bowhead whales was observed from an aircraft during 14 of 27 flights in the period 1-31 August 1982, mainly in the south-central Beaufort Sea northeast of Herschel Island, Yukon, Canada. Detailed behavioral observations were made while we circled over whales for 36.5 h, at distances up to approximately 200 km from home base at Tuktoyaktuk, N.W.T. The bowheads were 'presumably undisturbed' during 60% of the observation time (21.8 h), and these observations of 'normal behavior' are described here. Behavioral data were gathered in similar fashion to those obtained in 1980-81.

General Activities. -- During August 1982, most observations were of bowheads near the edge of the continental shelf in water >100 m deep. Whales dove for long periods, socialized little, and apparently spent much time feeding in the water column. This behavior was broadly consistent throughout August, although isolated instances of socializing and play activity occurred as well. Behavior was less variable than in 1980-81. In 1980, whales were often in shallow water close to shore, and appeared to feed in several different ways--at the surface, in the water column, and near the bottom. In 1981, most whales were in intermediate depths between the shallow water of 1980 and the deep water of 1982, and behavior was also more varied than in 1982.

Social Interactions. -- nudges, pushes, chases, and close proximity -- were observed much less often in 1982 than in 1980-81. No difference in the low level of socializing was noted from week to week, and all observed socializing was from 16:00-20:00 MDT. In 1980-81, there was less social activity late in August than earlier, and the peak of social activity bridged sidereal noon (15:00 MDT). No sexual interactions were recognized in 1982, although four chases may have been related to sexual activity. Aerial activity occurred sporadically and at low frequency throughout August. Three lone whales were seen breaching, and two presumed mothers tail slapped and flipper slapped while separated from their calves. A whale was seen playing with a log for 1.5 h; seismic noise was present at this time. A calf played within a line of surface debris for 12.3 min, and another calf played for 22.3 min within water marked by green dye. Both calves were alone at the surface while their mothers were presumably feeding below the surface.

Surfacing, respiration and dives. -- Intervals between blows, number of blows per surfacing, durations of surfacings, and durations of dives were measured 894, 77, 91, and 80 times, respectively, for whales that were apparently undisturbed. As in previous years, the interval between blows was the most consistent of the four variables over the season. The mean was 14.9 $\pm$ s.d. 8.66 s (n = 794) for non-calves, and was significantly higher than in 1980-81. Blows per surfacing and durations of surfacings were highly correlated, and the mean of 7.4 $\pm$ 5.11 blows per surfacing (n = 58) for non-calves was also higher than in 1980-81. The mean duration of surfacing was 2.05 $\pm$ 1.320 min (n = 70) for non-calves, almost twice as high as in 1980-81. Dive duration showed the greatest increase over previous years, however. The mean was 12.08 $\pm$ 9.153 min (n = 51) for non-calves, about four times higher than that recorded during 1980-81.

The number of blows per surfacing and the duration of surfacing were correlated with the durations of preceding and subsequent dives. The mean blow rate, or number of blows/min over a complete surfacing/dive sequence, was 0.70 ± s.d. 0.470 blows per min (n = 25 blow rates by 10 whales). Blow rates were generally higher in active whales than in inactive whales, and therefore appear to be good indicators of activity level.

Several factors were related to surfacing-dive-respiration characteristics. In 1982, the mean number of blows per surfacing, duration of surfacings, and duration of dives were all greater for whales in water >100 m deep than for whales in shallower water. There was no clear diurnal trend in any of the surfacing-dive-respiration characteristics. None of the characteristics differed significantly between socializing and non-socializing whales, but there was a trend: number of blows per surfacing, duration of surfacing, and duration of dive were all somewhat greater in non-socializing whales than in socializing whales. We believe that the non-socializing whales were mainly feeding below the surface, and that the longer cycle of surfacings and dives in non-socializing whales was a result of such feeding.

Mothers and Calves. -- The interval between blows was slightly longer and the number of blows per surfacing was slightly lower for calves than for non-calves. The number of blows per surfacing may have been biased by failure to detect some inconspicuous blows by calves. However, surface time was also shorter for calves than for non-calves. The calf vs. non-calf difference was less in 1982 than in earlier years, since in 1982 several calves spent much time at the surface, apparently waiting while their mothers fed in the water column. The clearest difference between calves and non-calves was in dive time: 6.82 ± s.d. 5.715 min (n = 29) for calves, or about one-half of the non-calf mean value. This was consistent with calf dive times relative to non-calf dive times in earlier years. During 1982, mean durations of dives by calves were four times longer than in 1980 and seven times longer than in 1981.

Maternal females and their calves blew at longer intervals than other whales, and the number of blows per surfacing was significantly lower for calves than for all other non-maternal whales. Number of blows per surfacing by maternal females was intermediate between the low value for calves and the higher value for non-maternal whales. The pattern of dive lengths differed from that of previous years. Mothers and calves dove for shorter lengths of time than did other whales, while in 1980-81 mothers made the longest dives. Calves dove for shorter periods than did any other whales.

Calves were encountered alone on the surface on four separate occasions, and these accounted for 40% of calf observation time in 1982. When calves were with their mothers, they often submerged toward the mother's teat region for brief intervals, presumably to nurse. During apparent nursing, calves usually blew only once between submergences.

Calls. -- Sounds of bowheads were analyzed from 30.6 h of sonobuoy tapes from 1982. Most sounds (90%) were low, tonal, frequency modulated (FM) calls similar to the sounds that southern right whales produce in long-distance contact situations. Loud low FM calls were heard especially well on one day when a mother and calf were about 375 m from each other, and this observation provides our best indication for acoustic communication between mother and calf. Complex calls heard in 1981 while whales were actively socializing were recorded much less often in 1982. The number of sounds recorded was much greater than during earlier years, and the rate of low FM calls increased by a factor of about 16 times over the rate in 1980-81. We hypothesize that loud low FM calls may have been more predominant in 1982 because whales usually were farther apart than in earlier years. Also, the deeper water where most whales were observed during 1982 may have increased the range of detectability of sounds.

Whales Near Ice. -- Whales were at times encountered in 1-40% ice (we usually did not fly over thicker ice cover). About 75% of the whales in ice showed little or no noticeable surface activity, and a low blow rate. We hypothesize that low activity in ice may be due in part to the generally calm water found among ice, although at present we have no proof for this assertion. Whales avoid ice during forward motion by diving under it rather than going around it.

Interspecific Associations. -- Ringed seals, white whales, gulls, terns, and phalaropes were occasionally seen near bowhead whales. Birds may have been feeding on prey stirred up by the whales, although we have no direct evidence of this. One gray whale was observed on 18 August 1982, feeding as close as 500 m from the nearest bowhead whale, but no interaction was observed between the gray whale and bowhead whales.

Relationships to Behavior in Other Species and Areas. -- Bowheads, right whales, and to a lesser degree gray whales, exhibit similarities in social activity and some feeding behaviors. Our studies have shown the behavior of bowheads in summer to be highly variable from year to year. Most of the socializing and feeding repertoire seen in the Canadian Beaufort Sea in summer has also been observed in migrating bowheads in the Alaskan Beaufort Sea in spring and fall. The main differences between summering and migrating bowheads appear to be quantitative rather than qualitative, i.e. different relative frequencies of behaviors in the two different areas, not differences in types of behaviors. Caution is necessary in comparing surfacing-dive-respiration characteristics recorded during this study with published results on bowheads in different areas (often based on data from different vantage points). Nevertheless, there are broad similarities, with differences apparently due mainly to the greater amount of time spent travelling in spring and fall than in summer.

Disturbance Responses of Bowheads, 1982

The report with the above title (Richardson, Wells and Würsig 1983c) describes the behavior of bowhead whales in the presence of actual or simulated industrial activities. In 1982, we emphasized studies of reactions to aircraft, seismic exploration and drilling, but collected some additional data concerning reactions to boats. This report presents the 1982 data and some previously unreported 1980-81 results in detail. It also re-examines some of the previously reported 1980-81 results for comparison and pooling with the 1982 data.

Methods in 1982 were very similar to those in 1980-81. The 1982 work was done in the Canadian Beaufort Sea throughout August. Both experimental and observational methods were used. During experiments, we tried to observe whales before, during and (when practical) after simulated industrial activity. In 1982, we conducted one boat disturbance experiment, two aircraft disturbance experiments, and three drilling noise playback experiments. Besides these experiments, we also observed whales in the presence and absence of aircraft, seismic exploration and drillships, and compared their behavior in these situations. Again in 1982, most observations were from a Britten-Norman Islander aircraft circling over the whales at an altitude of 457 m (1500 ft), which is high enough to avoid any major aircraft disturbance. Underwater sounds from whales and industrial sources were recorded via sonobuoys dropped from the aircraft and via hydrophones deployed from a boat. This boat was also used to conduct the playback and boat disturbance experiments.

The one **boat disturbance** experiment in 1982 was conducted in the presence of seismic noise with received level 132 dB//1 μPa. This trial replicated a 1981 experiment with the same 13-m boat in the presence of stronger seismic noise (about 150 dB). In both cases, the whales began to swim rapidly away as the boat closed to within 2-3 km. Thus, bowheads react strongly to an approaching boat even when they have already been exposed to intense sounds from seismic exploration before the boat approaches.

Over the 1980-82 period as a whole, reactions to close approach by boats were observed from the circling aircraft on 5 occasions, and additional data were obtained by trained observers on some boats. Bowheads responded to boats in two main ways. (1) When boats were nearby, bowheads altered their surfacing and diving pattern by decreasing the mean time at the surface per surfacing, the mean number of blows (respirations) per surfacing, and the mean dive duration. In 1980, mean surface times and blows/surfacing were reduced even in response to a stationary 16-m boat with its engines idling at a range of 3-4 km from the whales. (2) When boats closed to within 1-3 km, the whales, in addition to the above responses, swam rapidly away from the boat and scattered. Whales directly on the boat's track initially tried to outrun it, but usually turned to move off the track as the boat closed to within a few hundred metres. This flight reaction ceased when the vessel was 1-2 km beyond the whales, but increased spacing of individuals sometimes persisted until the vessel was farther away.

Short-term behavioral reactions to boats were more conspicuous than to any of the other types of industrial activities we studied. However, insofar as we could determine, none of the boat disturbances that we observed resulted in long-distance displacement. The effects of more frequent boat disturbance, or disturbance when whales and ships are both confined within leads, are unknown.

Reactions to an Islander **aircraft** were evaluated based on all data collected from 1980-82. New information from 1982 included (1) two experiments in which we circled above whales at 457 m (1500 ft) and then descended to 305 m (1000 ft), (2) a comparison of behavior observed from the aircraft and from a quiet, drifting boat, and (3) subjective interpretation of apparent reactions of whales to the observation aircraft on other occasions.

Based on results from 1980-82, we conclude that bowheads often dove precipitously in response to the Islander aircraft when it first approached at 305 m above sea level (a.s.l.), and occasionally did so when we approached at 457 m. In each of the four altitude experiments to date (two in 1982, two in 1981), mean interval between blows decreased when the aircraft descended from 610 m a.s.l. to 457 or 305 m, or from 457 m to 305 m. This tendency was not evident in the pooled data exclusive of the experiments or in small samples of data collected in the presence and absence of the aircraft. The discrepancy may reflect the greater sensitivity of the four controlled tests on particular bowheads. Excluding data from those experiments, mean lengths of time at the surface per surfacing were slightly reduced when the aircraft circled at 457-518 m relative to those when it circled at 610 m, but there was no clear evidence of effects on respiration or dive characteristics. In general, reactions to a circling aircraft were conspicuous if it was at 305 m, occasional but not major at 457 m, and undetectable at 610 m.

Work in 1981 showed that underwater noise from a Bell 212 helicopter was stronger than that from the Islander (Greene 1982). Thus, reactions of bowheads to such a helicopter might be stronger than to the Islander, or might occur at greater range. However, during straight-line passes at 152-610 m a.s.l. over a hydrophone, helicopter sound was detectable for only 16-27 s.

We observed bowhead behavior in the presence of noise from full-scale **seismic exploration** on four days in 1982 and four days in 1980-81. There was no clear evidence that these whales were attempting to move away from the seismic ships. Bowheads usually continued to produce their normal types of calls in the presence of seismic sounds.

Detailed comparisons of the surfacing and respiration behavior of bowheads in the presence and absence of seismic noise have provided inconsistent results. In some but not all incidents, there have been indications that the usual cycles of surfacing, respiration and diving were modified by the seismic activity. This was so on three occasions in August 1982 when bowheads were seen 40-73 km from a vessel firing airguns. The apparent effects were detectable only by a detailed quantitative analysis of the data, and were not conspicuous to experienced observers watching the animals. On other occasions, including two incidents when a seismic ship was firing sleeve exploders 13 and 6-8 km from whales, no similar effects on behavior were detected even by detailed numerical analysis.

Differences in seismic sound levels near the whales do not explain the apparent inconsistency in the results. Peak levels of seismic sounds near the whales on the three occasions in 1982 when effects appeared to be present were 107-133 dB//1 μPa, or some 15-40 dB above the ambient levels prevailing at those times in the 10-500 Hz band. Levels near the seemingly undisturbed whales 6-13 km from a seismic ship were higher, about 141-150 dB.

During two controlled experiments with one 40 cu in airgun fired 5 and 3 km from bowheads in 1981, we found slight indications of altered surfacing, respiration and diving cycles. The trends were consistent with those seen 40-73 km from full-scale seismic operations with airgun arrays. Also, during one of these experiments, the whales stopped calling.

We suspect that the apparent inconsistencies in the results concerning surfacing, respiration, diving and calling are a result of two main factors: (1) actual differences in the responses of the whales to seismic noise on different occasions, including possible habituation to ongoing seismic, and (2) difficulties in detecting subtle behavioral effects in the presence of great variability in natural behavior. However, the results show quite clearly and consistently that summering bowheads normally do not swim away from seismic vessels operating 6 km or more away. The importance of the subtler behavioral reactions that sometimes seem to occur is not known. Distributional evidence indicates that bowheads continue to use summering areas where seismic exploration has been in progress each summer for many years.

Drilling from artificial islands has not been in progress during our field seasons. However, we did see bowheads as close as 10-12 km from an operating drillship in 1982, and as close as 4 km in 1981. Industry personnel reported closer sightings. The strongest tonal sound from the drillship at 4 km range was about 111 dB//1 μPa at 278 Hz. There was no consistent indication of unusual behavior among whales observed within 20 km of drillships.

On two occasions in 1982, we completed controlled experiments in which we broadcast drilling noise into the water near whales whose behavior was observed both before and during the playback period. There was some indication that the whales increased their rate of dispersal away from the site of the underwater projector during the playback period. However, the sample size was small and the reactions were not as conspicuous as those to close approach by a boat.

No new information about reactions to **dredging** was obtained in 1982. In 1980, bowheads frequently were seen <5 km from an artificial island that was under construction by a suction dredge. We saw bowheads as close as 800 m from the operation, and industry personnel reported that one bowhead came closer than that. Sounds from the dredge were well above ambient out to at least 7.4 km from the dredge.

Overall, the results show that the behavior of bowheads can be affected markedly by the close approach of ships or aircraft. However, the whales seem to return to their normal activities soon after the ship or plane moves away. Reactions to industrial activities that continue for hours or days at a time, such as seismic exploration, drilling and suction dredging, are not nearly so obvious. Bowheads sometimes approach close enough to seismic vessels, drillships and dredges to be exposed to considerable industrial noise. When seen near these operations, bowheads do not seem to be trying to swim away, although there was an indication of dispersal during drilling noise playbacks. Whales remaining near industrial operations may, however, be subject to stress or other negative effects not evident from short-term behavioral observations. The possibility of long-term displacement is examined in a later section (Richardson et al. 1983a).

Characteristics of Waterborne Industrial Noise, 1982

The report with the above title (Greene 1983) documents the characteristics of the underwater sounds to which bowhead whales were exposed during the experiments and observations summarized above. Similar studies in 1980-81 had included measurements of underwater noise from a drillship, a suction dredge, a loaded hopper dredge underway, three types of aircraft (Twin Otter, Britten-Norman Islander, Bell 212 helicopter), several support vessels, and seismic survey signals from sleeve exploders (Greene 1982). Regression models for sound transmission loss in the shallow water were also derived. In 1982, measurements were made of seismic signals at close ranges (from 0.9-14.8 km), seismic signals from an airgun array at ranges of 52-75 km, sounds from a variety of activities at an artificial island (Tarsiut), sounds from a different drillship, and sounds from trailing suction hopper dredges dropping and picking up loads.

Sounds were recorded via sonobuoys dropped from the Islander aircraft and via hydrophones deployed beneath a sparbuoy floating near a drifting vessel--the MV 'Sequel'. In addition, previously recorded drillship sounds were projected underwater near bowheads in playback experiments to study any behavior changes that might occur.

The **seismic ship** 'Arctic Surveyor' used open-bottom gas guns in 1982. For ranges 0.9 to 14.8 km in water 9-11 m deep, we recorded peak levels corresponding to rms levels from 177 to 123 dB//1 µPa. Using a least squares regression fit to an equation with a spherical spreading loss term of 20 log(R), Greene derived an absorption loss term of 2.09 dB/km and a predicted level of 174.5 dB//1 µPa at 1 km; the standard error was 1.7 dB. Frequency content at the short ranges (to 1.9 km) was predominantly below 150 Hz; beyond 7.4 km the energy was predominantly above 150 Hz. Thus, low frequencies attenuated more rapidly in the shallow water. The low frequency energy (<100 Hz) probably travelled via a higher-velocity sub-bottom path; it arrived 70-135 ms (depending on range) before the higher frequency component, which presumably traveled via an in-water path.

Signals received from the 1410 cu in airgun array on 'GSI Mariner' varied considerably over short periods of time, but we recorded levels from 133 dB at 60 km to 110 db at 75 km. Transmission loss could not be modeled because data were recorded sporadically at different places and times.

Tarsiut Island was a caisson-retained **artificial island** in 23 m of water off the Mackenzie Delta. During two visits by 'Sequel', there were always four or more workboats, barges and tugs in the vicinity. Drilling had been completed before Greene's first visit on 6 August, but different activities contributed to varying noise levels. Sounds from pile driving using a vibrator on the opposite corner of Tarsiut from "Sequel's" position were not identified. At 1.1 km on two occasions, band levels for 10-500 Hz varied from 126-133 dB//1 µPa and there were several strong tones (e.g., 55 Hz at 113 dB, 115 Hz at 116 dB, and 132 Hz at 119 dB). At 0.46 km, the 10-500 Hz band level was 119 dB and the strong tones were 91 Hz at 104 dB and 121 Hz at 112 dB. It is not known which of the various noise sources in the area was responsible for each of these tones. Noise recorded 18.5 km west of Tarsiut 3 h later was generally indistingishable from natural ambient noise—the 10-500 Hz band level was 104 dB or 15 dB lower than 0.46 km from Tarsiut.

Drillship 'Explorer I' was not drilling during visits by 'Sequel', but other drillship sounds were recorded at two short ranges. Water depth was 17 m and the ship was 18 km from Tarsiut Island. While the drillship was 'logging', Greene measured a 10-500 Hz band level of 125 dB at a range of 170 m. The noise spectrum included several strong tones, including 88 Hz at 112 dB, 211 Hz at 118 dB, and 501 Hz at 108 dB. At 610 m, the 10-500 Hz band level was 113 dB and the strongest tone was at 88 Hz, 103 dB.

Sonobuoy recordings at ranges of 11 and 18.5 km from drillship 'Explorer III' while drilling showed no evidence of machinery noise.

Sounds of the **hopper dredge** 'Gateway' dropping her load in 12 m of water were recorded at a range of 1.5 km. The 10-500 Hz band level was 129 dB. Underway empty at a range of 1.06 km the level in the same band was also 129 dB. While stopped and not dumping at range 1.5 km, the 10-500 Hz band level was 120 dB. Hopper dredge 'Geopotes X' picking up a load at a range of 0.43 km produced a 10-500 Hz band level of 141 dB. We estimated that, at a standardized range of 1 km, 'Geopotes X' dredging was 5 dB noisier than 'Gateway' dumping (in the 10-500 Hz band).

The projected drillship sounds during the highest-level **playback experiment** achieved a maximum source level of 164 dB//1 μPa-m. At range 2 km, the 10-500 Hz band level was 109 dB and the dominant 275 Hz tone was 103 dB. Based on the drillship transmission loss model developed in 1981 for this tone, a level of 103 dB would be expected at a range of 7 km from the actual drillship, and a level of 117 dB would be expected at range 2 km.

Distribution of Bowheads and Industrial Activity, 1980-82

The report with this title (Richardson, Davis, Evans and Norton 1983a) reviews the distribution of bowheads summering in the eastern Beaufort Sea in recent years and discusses whether there have been any distributional changes attributable to oil exploration.

Detailed data on bowhead distribution in most of the Canadian Beaufort Sea have been collected only since 1980, and only from late July or early August to mid September. Sightings during the various studies conducted within this period are compiled onto a series of maps, one or two per 10-d period. Survey routes are also shown on these maps. Previously unreported distributional data from this and other LGL studies in 1980-82 are included, along with results compiled from all available reports by ourselves and others.

Industrial activities are also mapped. For each 10-d period, one map shows the sites of offshore drilling, dredging, etc., along with the approximate number of boat trips along each route. Another map for each 10-d period shows seismic lines shot during the period, plus locations of low-energy sounding. A third type of map shows helicopter traffic and ice conditions during the 1-10 and 22-31 August periods. 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 support traffic via boat and helicopter.

In **1980**, bowheads were more numerous close to shore than in the subsequent two years. Around 2 August, many moved into shallow waters off the central Mackenzie Delta, the main industrial area. Some were within 5 km from the island construction operation at Issungnak. Whales were scarce farther east off the Tuktoyaktuk (Tuk) Peninsula in early August, but moved into that area of lesser industrial activity in mid August. By late August, very large numbers were widely distributed off the Tuk Peninsula, many in water <20 m deep. Numbers off the Delta were somewhat reduced, but still high. Previous to late August, there was no survey coverage west of the Delta; in late August at least a few whales were present north of Herschel Island. In early September, fewer whales were found off the Tuk Peninsula, and they were farther offshore. Numbers off the Delta were much reduced, but whales were seen regularly near Herschel Island. Bowheads were first seen in Alaskan waters on 4 September.

In **1981**, survey coverage was more comprehensive and most bowheads remained farther offshore. In late July, most were either far offshore in pack ice or in Amundsen Gulf. In early August many moved south onto the outer continental shelf off the Mackenzie Delta, with lesser numbers off the Tuk Peninsula. None were seen near Issungnak where whales were abundant in early August 1980. In mid August the whales were more evenly distributed from Herschel Island to Cape Bathurst, mainly in waters >50 m deep, but there was a concentration in shallower water off the central Delta. Some of the latter animals were <10 km from an artificial island and drillship. In early September, most bowheads were still in Canadian waters, with many off the Tuk Peninsula and Herschel Island and lower densities elsewhere. The first sighting in Alaskan waters was on 7 September.

In **1982,** most bowheads were far enough offshore or west to be outside the main industrial area. In early August, the only sightings in the Canadian Beaufort Sea were on the outer shelf off the western Delta and Yukon, and many were moving west. Some bowheads were seen in the Alaskan Beaufort as early as early August. In mid August, there was a major concentration near Herschel Island, with low densities off the Delta and Tuk Peninsula. In late August, many bowheads remained off Herschel Island; others were along the shelf break off the western Delta and on the outer shelf off the eastern Tuk Peninsula. In early September, many were still near Herschel Island, with a few on the outer shelf off the Delta and Tuk Peninsula.

Most of the Canadian Beaufort Sea was not surveyed for bowheads before 1980. However, a longer series of data is available for the area of most intense industrial activity off the eastern Mackenzie Delta. Island construction and traffic to drillships farther north have occurred off the Delta each summer since 1976, and seismic exploration since 1971. In 1976 and 1977, many bowheads entered shallow waters off the Delta in early August. They did not do so in 1978 or 1979. Many whales occurred off the eastern part of the Delta in 1980, but few were there in 1981 and almost none in 1982. Given the reappearance of many whales off the Delta in 1980, there is no clear trend for decreasing numbers in that small area. For other parts of the Canadian Beaufort Sea, the lack of data from years before 1980 makes it impossible to assess whether the 1981 and 1982 distributions were unusual.

In 1980, 1981 and 1982, seismic exploration occurred over much of the Canadian Beaufort Sea -- both within and beyond the main industrial area. Numerous bowheads were in areas ensonified by seismic noise in 1981 and 1982 as well as in 1980.

Whether or not industrial activities affect bowhead distribution in summer, bowhead movements probably depend strongly on the distribution and abundance of zooplankton. Factors affecting zooplankton in the eastern Beaufort Sea are poorly known, but probably include the variable volume and movement of fresh water from the Mackenzie River, and hydrodynamic phenomena at the shelf break and the ice edge. The variable distribution of ice probably also has direct effects on whale distribution.

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NORMAL BEHAVIOR OF BOWHEADS, 1982*

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ABSTRACT

Behavior of bowhead whales was observed from an aircraft during 14 of 27 flights in the period 1-31 August 1982, mainly in the south-central Beaufort Sea northeast of Herschel Island, Yukon, Canada. Detailed behavioral observations were made while we circled over whales for 36.5 h, at distances up to approximately 200 km from home base at Tuktoyaktuk, N.W.T. The bowheads were 'presumably undisturbed' during 60% of the observation time (21.8 h), and these observations of 'normal behavior' are described in the present report. This represents the third consecutive year of detailed behavioral observations of bowhead whales in the eastern Beaufort Sea in summer, and behavioral data were gathered in similar fashion during all three years.

During August 1982, most observations were of bowheads near the edge of the continental shelf in water >100 m deep. Whales dove for long periods, socialized little, and apparently spent much time feeding in the water column. This behavior was broadly consistent throughout August, although isolated instances of socializing and play activity occurred as well. Behavior was less variable than in 1980-81. In 1980, whales were often in shallow water close to shore, and appeared to feed in several different ways--at the surface, in the water column, and near the bottom. In 1981, most whales were in intermediate depths between the shallow water of 1980 and the deep water of 1982, and behavior was also more varied than in 1982.

Social interactions--nudges, pushes, chases, and close proximity--were observed much less often in 1982 than in 1980-81. No difference in the low level of socializing was noted from week to week, and all observed socializing was from 16:00-20:00 MDT. In 1980-81, there was less social activity late in August than earlier, and the peak of social activity bridged sidereal noon (15:00 MDT). No sexual interactions were recognized in 1982, although four chases may have been related to sexual activity. Aerial activity occurred sporadically and at low frequency throughout August. Three lone whales were seen breaching, and two presumed mothers tail slapped and flipper slapped while separated from their calves. A whale was seen playing with a log for 1.5 h; seismic noise was present at this time. A calf played within a line of surface debris for 12.3 min, and another calf played for 22.3 min within water marked by green dye. Both calves were alone at the surface while their mothers were presumably feeding below the surface.

In 1982, we found no synchrony in orientations of presumably undisturbed whales spread over a large area. However, during two flights when appropriate data were gathered, there was synchrony in surfacing and diving between groups of whales >75 m apart.

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 within a single observation session, but we obtained no known resightings between days in 1982.

Intervals between blows, number of blows per surfacing, durations of surfacings, and durations of dives were measured 894, 77, 91, and 80 times, respectively, for whales that were apparently undisturbed. As in previous years, the interval between blows was the most consistent of the four variables over the season. The mean was 14.9 ± s.d. 8.66 s (n = 794) for non-calves, and was significantly higher than in 1980-81. Blows per surfacing and durations of surfacings were highly correlated, and the mean of 7.4 ± 5.11 blows per surfacing (n = 58) for non-calves was also higher than in 1980-81. The mean duration of surfacing was 2.05 ± 1.320 min (n = 70) for non-calves, almost twice as high as in 1980-81. Dive duration showed the greatest increase over previous years, however. The mean was 12.08 ± 9.153 min (n = 51) for non-calves, about four times higher than that recorded during 1980-81.

The interval between blows was slightly longer and the number of blows per surfacing was slightly lower for calves than for non-calves. The number of blows per surfacing may have been biased by failure to detect some inconspicuous blows by calves. However, surface time was also shorter for calves than for non-calves. The calf vs. non-calf difference was less in 1982 than in earlier years, since in 1982 several calves spent much time at the surface, apparently waiting while their mothers fed in the water column. The clearest difference between calves and non-calves was in dive time: 6.82 ± s.d. 5.715 min (n = 29) for calves, or about one-half of the non-calf mean value. This was consistent with calf dive times relative to non-calf dive times in earlier years. During 1982, mean durations of dives by calves were four times longer than in 1980 and seven times longer than in 1981.

The number of blows per surfacing and the duration of surfacing were correlated with the durations of preceding and subsequent dives. The mean blow rate, or number of blows/min over a complete surfacing/dive sequence, was 0.70 ± s.d. 0.470 blows per min (n = 25 blow rates by 10 whales). Blow rates were generally higher in active whales than in inactive whales, and therefore appear to be good indicators of activity level.

Several factors were related to surfacing-dive-respiration characteristics. In 1982, the mean number of blows per surfacing, duration of surfacings, and duration of dives were all greater for whales in water >100 m deep than for whales in shallower water. There was no clear diurnal trend in any of the surfacing-dive-respiration characteristics. Maternal females and their calves blew at longer intervals than other whales, and the number of blows per surfacing was significantly lower for calves than for all other non-maternal whales. Number of blows per surfacing by maternal females was intermediate between the low value for calves and the higher value for non-maternal whales. The pattern of dive lengths differed from that of previous years. Mothers and calves dove for shorter lengths of time than did other whales, while in 1980-81 mothers made the longest dives. Calves dove for shorter periods than did any other whales. None of the characteristics differed significantly between socializing and non-socializing whales, but there was a trend: number of blows per surfacing, duration of surfacing, and duration of dive were all somewhat greater in non-socializing whales than in socializing whales. We believe that the non-socializing whales were mainly feeding below the surface, and that the longer cycle of surfacings and dives in non-socializing whales was a result of such feeding.

Calves were encountered alone on the surface on four separate occasions, and these accounted for 40% of calf observation time in 1982. When calves were with their mothers, they often submerged toward the mother's teat region for brief intervals, presumably to nurse. During apparent nursing, calves usually blew only once between submergences.

Sounds of bowheads were analyzed from 30.6 h of sonobuoy tapes. The majority of sounds (90%) were low, tonal, frequency modulated (FM) calls similar to the sounds of southern right whales produced in long-distance contact situations. Loud low FM calls were heard especially well on one day when a mother and calf were about 375 m from each other, and this observation provides our best indication for acoustic communication between mother and calf. Complex calls heard in 1981 while whales were actively socializing were recorded much less often in 1982. The number of sounds recorded was much greater than during earlier years, and the rate of low FM calls increased by a factor of about 16 times over the rate in 1980-81. We hypothesize that loud low FM calls may have been more predominant in 1982 because whales usually were farther apart than in earlier years. Also, the deeper water where most whales were observed during 1982 may have increased the range of detectability of sounds.

Whales were at times encountered in 1-40% ice (we usually did not fly over thicker ice cover). About 75% of the whales in ice showed little or no noticeable surface activity, and a low blow rate. We hypothesize that low activity in ice may be due in part to the generally calm water found among ice, although at present we have no proof for this assertion. Whales avoid ice during forward motion by diving under it rather than going around it.

Ringed seals, white whales, gulls, terns, and phalaropes were occasionally seen near bowhead whales. Birds may have been feeding on prey stirred up by the whales, although we have no direct evidence of this. One gray whale was observed on 18 August 1982, feeding as close as 500 m from the nearest bowhead whale, but no interaction was observed between the gray whale and bowhead whales.

Bowheads, right whales, and to a lesser degree gray whales, exhibit similarities in social activity and some feeding behaviors. Our study has shown that the behavior of bowheads in summer is highly variable from year to year. Most of the socializing and feeding repertoire seen in the Canadian Beaufort Sea in summer has also been observed in migrating bowheads in the Alaskan Beaufort Sea in spring and fall. The main differences between summering and migrating bowheads appear to be quantitative rather than qualitative, i.e. different relative frequencies of behaviors in the two different areas, not differences in types of behaviors. Caution is necessary in comparing surfacing-dive-respiration characteristics recorded during this study with published results on bowhead whales in different areas (often based on data from different vantage points). Nevertheless, there are broad similarities, with differences apparently due mainly to the greater amount of time spent travelling in spring and fall than in summer.

INTRODUCTION

This study was a continuation of the research on the normal, undisturbed behavior of the bowhead whale, Balaena mysticetus, which was conducted in the summers of 1980 and 1981 and presented by Würsig et al. (1982). As in the previous two years, the observations of bowhead behavior in the summer of 1982 were conducted as part of a broader analysis of the potential effects on these whales of offshore oil and gas exploration and development in the Beaufort Sea. To interpret the 1982 studies of the possible effects of industrial activities on behavior, it was necessary to examine the normal behavior of bowhead whales during the same season.

As in the previous two years, the 'normal behavior' study in 1982 was one of several tasks comprising the overall study. The other tasks were studies of the responses of bowheads to various offshore industrial activities (Richardson et al. 1983b), studies of the characteristics of waterborne industrial noise (Greene 1983), and an analysis of the distribution of summering bowheads in relation to industrial activity from 1980 through 1982 (Richardson et al. 1983a). Because the work in 1982 was planned as a continuation of two previous years of study, frequent reference will be made to the previous report on normal behavior (Würsig et al. 1982). Detailed repetition of the results from 1980 and 1981 will be minimized. For a review of previously existing knowledge of the behavior of bowhead whales, see Fraker and Richardson (1980) and Würsig et al. (1982).

Objectives

The two main objectives of the 'Normal Behavior' task for 1982 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 interpreted, and (2) to provide additional information about normal behavior, with emphasis on aspects not studied in detail in 1980-81.

Additional pre-disturbance 'control' information was considered essential because the 1980-81 studies showed that bowhead behavior is quite variable. To recognize and evaluate disturbed behavior, it is desirable to obtain observations of 'presumably undisturbed' whales in situations differing only by the absence of the source of presumed disturbance.

The second main objective of the normal behavior study in 1982 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. The topics to be emphasized in 1982 were the behavior of calves and their mothers, the behavior of bowheads when in ice, and comparisons with migrating bowheads. An analysis of bowhead sounds was an important objective of the study, as in previous years, because of the widely assumed significance of waterborne sounds to whales. In 1982, detailed spectrographic analysis of bowhead sounds was de-emphasized, since previous work appeared to have characterized the usual types of calls. Instead, we emphasized measurements of the rate at which each type of call was produced in various behavioral contexts, and in the presence vs. absence of industrial activity.

Approach

The general approach in 1982 was very similar to that in 1980-81. 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, 1982' (Richardson and Würsig 1983). The only major difference in approach during 1982 was that no shore-based observations were collected this year.

Field work extended from 1-31 August 1982 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 normal 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 almost all 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 under such conditions may not represent undisturbed behavior and have been excluded from this 'Normal Behavior' section.

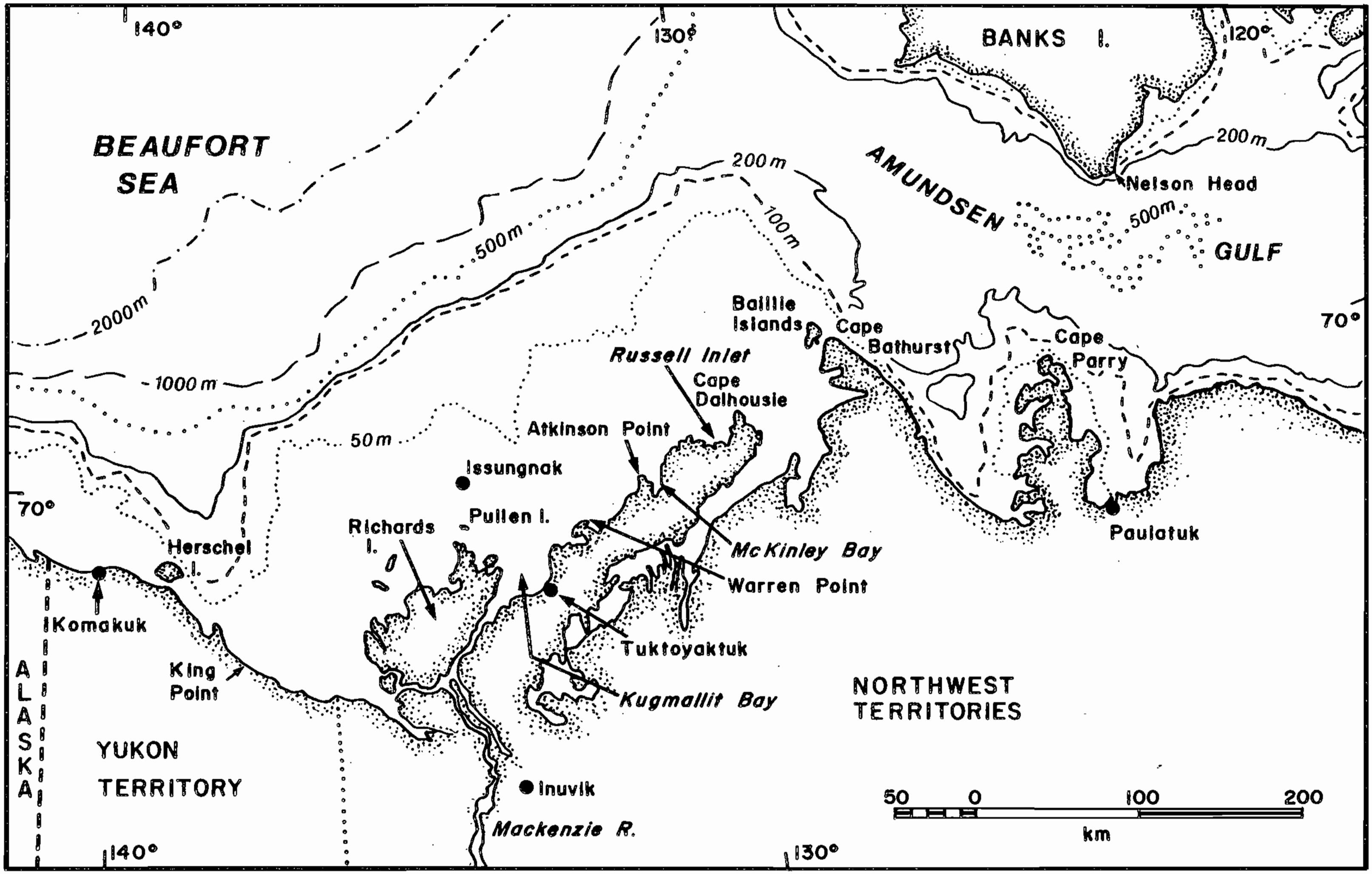

FIGURE 1. The eastern Beaufort Sea region, showing locations mentioned in text and bathymetry.

METHODS AND DATA BASE

Aerial Observations

As in the previous two years, most of the behavioral observations were made from the air, from a Britten-Norman Islander aircraft based at Tuktoyaktuk. The Islander has two piston engines, high wing configuration, low stall speed, radar altimeter and forward-looking radar. The plane was also equipped with an OnTrac VLF/Omega navigation system, which continuously computed the position of the aircraft, usually within 1.8 km of the real position. Positions and flight tracks were recorded manually from the VLF/ Omega system. Sonobuoys (AN/SSQ-57A) were deployed and monitored from the aircraft in order to record waterborne sounds from bowheads and industrial sources (details in 'Characteristics of Waterborne Industrial Noise, 1982' section, Greene 1983). 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 fluoroscein 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 1982 we made 27 flights between 1 and 31 August, and we made behavioral observations of bowheads during 14 of the flights. With the exception of occasions 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. Flight duration per flight was typically 4 to 5.5 hours. Total flight duration in 1982 was 122.1 hours, and we were circling over bowhead whales for 36.5 hours. The latter figure is higher than the corresponding value for either 1980 or 1981, despite the scarcity of bowhead whales close to Tuktoyaktuk and the briefer field period in 1982 than in 1981.

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 m (1500 ft) above sea level (a.s.l.), and at 185 km/h. While circling over whales, we usually reduced speed to about 148 km/h. Bowheads rarely appeared to be disturbed by the aircraft when it remained at or above 457 m (see 'Disturbance' section, Richardson et al. 1983b).

The distributions of bowhead sightings by 10-day periods in 1982, and also in 1980-81, are given in an accompanying section (Richardson et al. 1983a). Bowheads were more difficult to locate in 1982 than in either of the two previous years. Extensive reconnaissance flights during this and other simultaneous projects in August 1982 showed that bowheads were almost totally absent from the shallow waters off the Mackenzie Delta and Tuktoyaktuk Peninsula where they had been so numerous in August 1980 and, to a lesser degree, mid-late August 1981 (Richardson et al. 1983a). Although a few whales were seen elsewhere, all detailed behavioral observations in 1982 were obtained 175 km or more to the west and northwest of Tuktoyaktuk in water 48-550 m deep, mainly off Herschel Island and far offshore from the western part of the Mackenzie Delta (see Fig. 1).

The aircraft crew consisted of four biologists and the pilot, all of whom had considerable previous experience in locating and observing bowhead whales. The same five individuals comprised the aircraft crew during all flights in 1982. Three biologists were seated on the right side of the aircraft, which circled to the right when we were obtaining behavioral observations. As in 1981, biologists seated in the right front (co-pilot's) seat and in the seat directly behind it were responsible for describing behavioral observations, which were recorded onto audiotape. This information was 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, use of the radar to measure distances to industrial activities, and overall direction of the work. A fourth biologist, seated in the left rear seat, searched for bowheads on the left side of the aircraft, launched sonobuoys and dye markers, and operated sound recording equipment. Contrary to the procedure in 1981, behavioral observations were not transcribed onto paper during the flights. The biologists and pilot were in constant communication via intercom.

We encountered consistently fewer bowheads per flight in 1982 than in the two previous years. At times it was difficult to assess their basic behavior patterns, but we obtained consistent data in 14 categories:

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. Headings and turns of each whale in degrees true;
6. Distances between individuals (estimated in whale lengths);
7. Duration of time at surface and sometimes duration of dive;
8. Timing and number of respirations, or blows;
9. Mouth open or closed;
10. Underwater blow (releasing large clouds of bubbles underwater);
11. Defecation;
12. Socializing, and probable nursing by calves;
13. Aerial activity: breaches, tail slaps, flipper slaps, lunges, rolls;
14. Type of dive: fluke out, peduncle arch, pre-dive flex.

Descriptions of the behaviors mentioned above appear later in this report. In 1982, we looked for but did not see several other types of behavior recorded in earlier years: surfacing with mud streaming from the mouth, near-surface skim feeding, and probable mating.

The 14 flights during which we made behavioral observations in 1982 are summarized in Table 1. The distributions of behavioral observations by hour of day and water depth are presented in Figures 2 and 3. Observations in 1982 were usually in deeper water than in 1980 or 1981.

The observation times in Figures 2 and 3 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. 1983b). Whales were classified as 'presumably undisturbed' only if

Table 1. A summary of aerial observations of bowhead behavior, 1982.

Date (1982)	Time over Bowheads: Start (MDT)	Stop (MDT)	Total hours	Distance from Shore & Location	Depth of Water* (m)	Estimated Number of Whales: adults	calves	Est. area under obs.** (km^2)	Disturbance	General Behavior
1 Aug	10:53	12:28	1.6	58 km north north-east of Herschel I.	296	1	0	15	Seismic assumed	Whale playing with log entire time
7 Aug	10:03	11:07	1.1	110 km northeast of Herschel I.	65	6-7	0	190	Seismic	All whales travelling west, medium to rapid speed
	11:39	12:21	0.7	118-122 km northeast of Herschel I.	365	2	0	80	Seismic assumed	Stationary, or slow travel
8 Aug	17:26	19:50	2.4	54-61 km northeast of Herschel I.	150-155	5	1	60	Aircraft experiment	Mother-calf pair, observed for over 2 h, stationary and slow travel
14 Aug	16:03	16:40	0.6	70-72 km northeast of Herschel I.	68	1-2	0	15	None known	-
	17:11	18:02	0.9	54-56 km northeast of Herschel I.	75	1-2	0	190	None known	-
	18:09	19:11	1.0	49-54 km north north-east of Herschel I.	186	2	1	50	None known	Possible nursing
16 Aug Flt #1	13:54	15:20	1.4	27-32 km northeast of Herschel I.	146-160	5	1	130	Boat experiment; seismic	Possible nursing
	15:34	17:18	1.7	35-39 km northeast of Herschel I.	159-165	6-9	2	80	Boat experiment; seismic	Some socializing, stationary and slow travel
16 Aug Flt #2	21:16	23:20	2.1	26-30 km northeast of Herschel I.	148-157	5-7	0	50	Drillship playback experiment	Slow travel, some rapid travel during play-back experiment
18 Aug	15:21	18:41	3.4	15-20 km east of Herschel I.	125	8-10	2-4	50	Drillship playback experiment; seismic	Slow to rapid travel, some aerial activity and some socializing
19 Aug Flt #1	10:22	12:58	2.6	17 km northeast of of Herschel I.	150	7+	2-3	25	Drillship playback experiment	Slow travel, some nursing, calf moves along windrow of debris
19 Aug Flt #2	16:56	19:31	2.6	24-28 km east of Herschel I.	112	8	2	20	None known	Some socializing, possible nursing

Continued...

Table 1. Concluded.

Date (1982)	Time over Bowheads: Start (MDT)	Stop (MDT)	Total hours	Distance from Shore & Location	Depth of Water* (m)	Estimated Number of Whales: adults	calves	Est. area under obs.** (km^2)	Disturbance	General Behavior
23 Aug	16:27	18:57	2.5	135 km northeast of Herschel I.	380	8-10	2	15	None known	Socializing, nursing, calf moves within area of diffused dye marker
24 Aug Flt #1	10:18	12:00	1.7	136-140 km northeast of Herschel I.	400-470	5-7	1	20	None known	Slow to rapid travel, whales apparently leave this area during the observation time
	12:15	14:10	1.9	146-149 km northeast of Herschel I.	389	1	1	60	None known	Medium speed by mother-calf pair, apparent nursing
24 Aug Flt #2	19:04	19:25	0.4	8-12 km east of Herschel I.	80-100	4-5	0	70	None known	Whales quiescent in brash ice
	19:36	19:55	0.3	8-12 km east of Herschel I.	74	4-5	0	70	None known	Whales quiescent in brash ice
24 Aug Flt #2	20:44	21:34	0.8	43 km northwest of Herschel I.	48	4-5	0	10	None known	Whales quiescent in brash ice
31 Aug Flt #1	10:15	13:47	3.5	126-132 km northeast of Herschel I.	550	1	0	80	Aircraft experiment	Slow to medium speed travel towards north
31 Aug Flt #2	17:41	20:55	3.2	134-137 km northeast of Herschel I.	150-390	2	0	160	None known	Stationary and slow travel

* Location was determined from the VLF navigation system on the aircraft, and water depth for the corresponding latitude and longitude was taken from hydrographic charts.
** This is the approximate area over which the aircraft circled and within which the 'Estimated Number of Whales' were found.

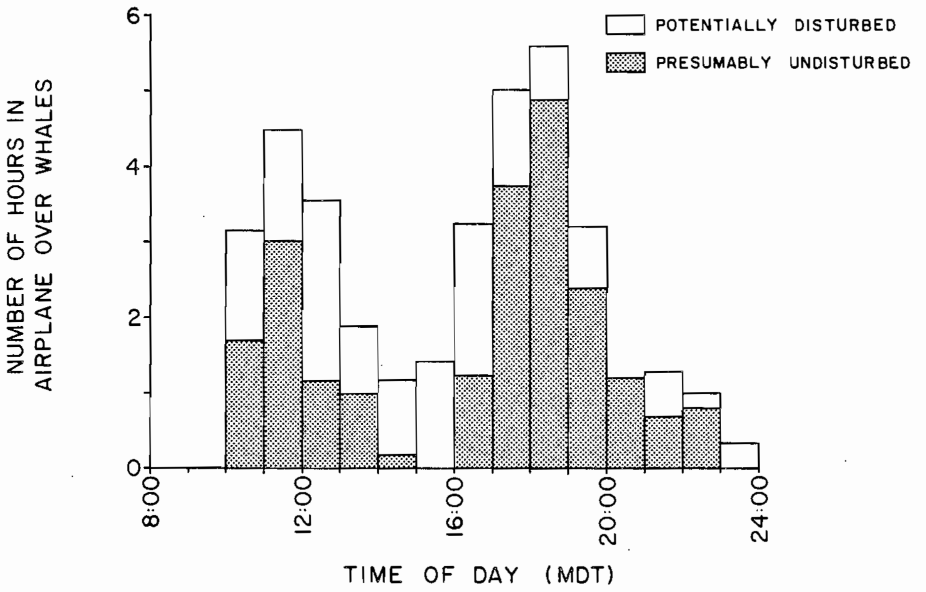

FIGURE 2. Hourly distribution of behavioral observation time from the air, 1-31 August 1982. Time spent over presumably undisturbed whales is distinguished from time spent over potentially disturbed whales.

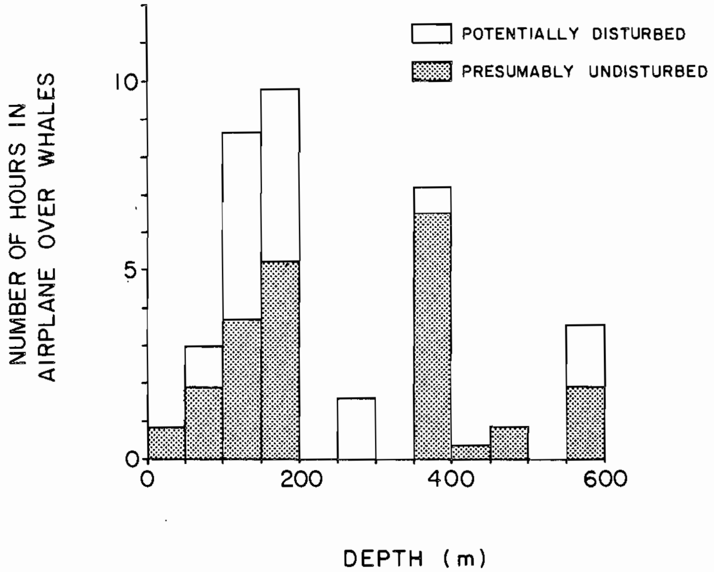

FIGURE 3. Distribution of behavioral observation time from the air by depth of water for 1982. Time spent over presumably undisturbed whales is distinguished from time spent over potentially disturbed whales.

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 our 12-m boat was nearby; the whales were considered to be presumably undisturbed if the boat had been drifting quietly with engines off for at least 30 min. In 1982, 36.5 h were spent circling over bowheads; 21.8 h (60%) of this time was '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 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:

Year	Surfacing Records	Dive Records	Total Records
1980	562	223	785
1981	778	223	1001
1982	312	141	453

These counts include both presumably undisturbed and potentially disturbed whales. The low numbers of records for 1982 are only partly a reflection of the difficulty in locating bowheads in 1982. In addition, whales tended to be found in smaller groups in 1982 than in previous years and tended to dive for longer periods. Both of these differences in behavior resulted in fewer records of surfacings and dives per hour of observation.

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-m diesel vessel 'Sequel' based at Tuktoyaktuk. The 'Sequel' could travel at a maximum speed of about 13-15 km/h and required about 24 h to travel from Tuktoyaktuk to the usual locations of bowheads in 1982. The boat crew consisted of one biologist making behavioral observations, one acoustician to obtain underwater recordings and to play back industrial noise, and the captain. Because behavioral observations from the boat pertained mostly to experimental disturbance trials, they are detailed in the 'Disturbance' section of this report.

RESULTS AND DISCUSSION

Descriptions of Behaviors

Surface-dive Sequence

While migrating, bowheads dive for long periods. Carroll and Smithhisler (1980) observed a mean dive time in migrating bowheads of 15.6 $\pm$ s.d. 5.0 min, n = 63. Migrating bowheads intersperse these long dives with a series of short dives punctuated by brief surface stays when the whales respire. Rugh and Cubbage (1980) reported for migrating bowheads a mean duration of 17.9 $\pm$ s.d. 2.3 s, n = 145, for the short dives and 6.1 $\pm$ s.d. 0.5 s, n = 112, for the brief surfacings. The long dives are often called sounding dives, while the shorter dives in between the brief surfacings for a breath have been called series dives (Rugh and Cubbage 1980).

In the Beaufort Sea in summer, the surfacing and dive behavior of bowhead whales is somewhat different. The whales spend much time feeding and socializing and relatively little time travelling (Würsig et al. 1982). Their sounding dives may be short or long, depending on their activity, but the intervening time at the surface for respiration is less often punctuated by short series dives. That is, when whales come to the surface after a long dive, they usually respire several times before diving again. In our analysis, therefore, we describe only one kind of dive, the deep or sounding dive. If a whale remained visible from the air, we did not consider its surfacing to be interrupted by shallow dives between blows. Thus, we ignored many of the shallow submergences that observers working from low vantage points on ice, shore, or boat would have called series dives. Nonetheless, we did record many brief submergences as dives, since whales often important to understand the effect of vantage point on the interpretation of surfacings and dives and to take care when comparing data collected from different vantage points.

Blow

A blow is an exhalation of air by a whale, and it can occur above as well as below the surface. Underwater blows were rare in 1982, and most surface blows were probably immediately followed by an inhalation. Blows may be forceful and highly visible as a white cloud, or they may be so weak as to be undetectable. Blows of calves can be especially difficult to see, and we may have missed some blows of calves in spite of careful observation through binoculars. Only once in 1982 did we notice two separate jets to a blow, appearing first from one nostril and then the other.

The detectability of blows depends in part on the amount of water collected around the blowholes. The first blow after a surfacing usually appears very strong, probably because it is a forceful exhalation and because of the presence of water above the blowholes just after surfacing. On calm days and when whales lie at the surface with the blowholes exposed, the blowholes are relatively dry and blows may be especially difficult to detect.

Pre-dive Flex

The pre-dive flex is a distinctive concave bending of the back seen about 3-7 s before many dives. The whale flexes its back by about 0.5 to 1 m, so that the snout and tail disrupt the surface, and considerable whitewater is created at these two points. The whale then straightens its back and lies momentarily still before arching the back convexly as it begins its roll forwards and down. The pre-dive flex is seen from low vantage points as an abrupt lifting of the head, since the flukes apparently only touch the water surface from below.

During 1982, pre-dive flexes occurred in presumably undisturbed non-calves before 32 of 132 dives (24.2% of the time), with this behavior occurring more often later in the month of August than earlier (Table 2). Dives following pre-dive flexes were, on the average, about twice as long as

Table 2. Incidence of dives preceded by a pre-dive flex among presumably undisturbed non-calf whales early and late in August, 1982. The frequency of occurrence is significantly higher after 19 August (chi-square = 4.29, df = 1, $0.025<p<0.05$).

	Up to 19 August '82	After 19 August '82	Total
Dives with pre-dive flex	9	23	32
Dives without pre-dive flex	49	51	100
Total	58	74	132

dives without pre-dive flexes (pre-dive flex dive mean = 19.00 $\pm$ s.d. 7.877 min, n = 13; no flex dive mean = 10.15 $\pm$ s.d. 7.465 min, n = 36); the difference was statistically significant (Mann-Whitney U = 97.5, $p<0.01$). Five dives were preceded by two pre-dive flexes, with the flexes separated by a blow, and two dives were preceded by three flexes. We have no data on the durations of the dives that followed these multiple flexes.

Dive

During the dive, which can at times be predicted by the pre-dive flex, the whale makes its body convex and pitches forward and down. If the angle of submergence is steep, the tail is usually raised above the surface; if not, the tail may remain below or just touch the surface. Rarely do bowheads sink down without visibly arching the back.

The duration of a dive was measured from the time a whale left the surface to the time it returned to the surface. When a whale sank below the surface but remained visible, the incident was scored as a dive if the whale remained below the surface for >1 min, but not if it resurfaced within 1 min. Dive durations when whales disappeared could only be measured when we identified the whale by its body markings both before and after the dive.

Fifty-nine of 138 dives (42.8%) were preceded by raised flukes. Of the 32 dives preceded by one or more pre-dive flexes, 21 also showed raised flukes. These two pre-dive behaviors occurred together more frequently than would be expected by chance (chi-square = 3.94, $p<0.05$, df = 1). It is, therefore, of little surprise to find that dives with raised flukes were significantly longer than those not preceded by raised flukes (raised flukes dive mean = 18.67 $\pm$ s.d. 9.966 min, n = 12; flukes not raised dive mean = 10.05 $\pm$ s.d. 6.956 min, n = 38; Mann-Whitney U = 114, $p<0.01$).

There was no difference in duration of surfacing for surfacings with and without raised flukes. Surfacings including pre-dive flexes tended to be longer than those without pre-dive flexes (3.09 $\pm$ s.d. 1.038 min, n = 14, vs. 1.79 $\pm$ 1.284 min, n = 52; t = 3.50, df = 64, $p<0.001$). There was no discernible relationship between these pre-dive behaviors and water depth.

Tail Beats

A whale moving rapidly at or slightly below the surface often leaves a trail of circular surface disturbances representing the locations where the flukes change direction from their upward to their downward swing. These circles, termed fluke tracks and caused by upward moving water, are seen in all species of whales when they are swimming close to the surface and can be used to count the number of strokes the whale uses to propel itself a given distance. In bowheads, each tail beat near the surface propelled the animal forward by approximately one whale length, or about 15 m.

Aerial Activity

Aerial activity in bowheads consisted of breaching, forward lunging, tail slapping, pectoral flipper slapping, and rolling actively at the surface while creating whitewater with the body or extremities (see Würsig et al. 1982 for a more thorough description). In 1982, there was little aerial activity; it is described in a later section.

Social Interactions

Behavior was termed social when whales appeared to be pushing, nudging, or chasing each other or when they were within one-half body length of one another. This definition combines both active socializing and times when whales were less active but closely aggregated. We recognize that animals 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. Interactions between mothers and calves and between whales skim feeding in close proximity (e.g., in echelons) were not considered to be instances of socializing for our analyses and were treated separately. Details of social behavior are given in a later section.

Adult-Calf Pairs

Calves of the year are a light tan color, distinct from the dark black of non-calf bowheads. An adult that remained close to a calf was assumed to be the calf's mother. For the closely related southern right whale (*Eubalaena australis*) in winter, Payne and Dorsey (in press) found that in unambiguous adult-calf pairs, the adult was always a female and that identified calves were always seen with the same individual female. At times we saw apparent nursing as calves submerged briefly, oriented toward the teat region of the adult. In 1982, we made longer observations of calves than in either 1980 or 1981.

The relative lengths of six calves measured from videotape sequences recorded during August 1981 were a mean of 0.57 $\pm$ s.d. 0.052 adult body lengths (Würsig et al. 1982). Many of the calves we observed in August 1982 appeared to be smaller. This is corroborated by the fact that the lengths of calves measured from calibrated vertical photographs obtained by other LGL personnel in August-early September 1982 were 4.1-7.6 m, or 33-45% (mean 41%) of the length of the accompanying adult (Davis et al. 1983). It may be that births in 1981 occurred earlier than in 1982.

It is easy to identify a calf as young-of-the-year when it is beside an adult. When calves are alone, however, as they were often encountered in 1982, it is more difficult to recognize them as young-of-the-year, since the adult is not visible for size and shading comparisons. Behavior of calves and accompanying adults will be described in detail below.

Feeding Behaviors

Bowheads have been seen skim feeding at or just below the surface, and near-bottom feeding has been suggested when bowheads surface with muddy water emanating from their mouths. Water-column feeding is hypothesized when whales dive for long periods of time and stay at the surface for only the relatively brief time necessary to complete a blow sequence. A fourth possible feeding type, termed mud-tracking, probably represents whales churning up bottom sediment incidentally while they feed in shallow water. Würsig et al. (1982) provide more detailed descriptions of these behaviors.

During 1982, little direct evidence for feeding was noted. We saw no skim feeding at the surface, and only noticed nine isolated instances when a whale's mouth appeared to be open slightly. These brief, slight openings of the mouth contrast sharply with the sustained large gapes observed in 1980 and 1981, where the lower jaw at times hinged open up to an angle of about 60° from the upper jaw. It is likely that an occasional open mouth does not represent feeding. In southern right whales, Payne (in press) has observed mouth opening that he interprets as yawning following sleep.

We saw only one case of defecation (by a lone whale playing with a log) in 1982. Because we can only observe defecations by whales at the surface, we compared the rate of defecation in each year in reference to the number of whale-hours of observation at the surface. In 1982, there were about 0.09 defecations per whale-hour at the surface, as opposed to 0.73 in 1981 and 2.29 in 1980 (chi-square = 27.58, df = 2, $p<0.001$):

Year	# defecations seen	Whale-hours of observ.*	Defecations per whale-h
1980	23	10.03	2.29
1981	11	14.98	0.73
1982	1	10.95	0.09

* Including only periods when whales were visible at surface.

Since whale-hours of observation refer to the amount of time whales were observed at the surface, this decrease in observations of defecations could result either from decreased defecation (indicative of less feeding) or from an increasing tendency to defecate under the surface where we could not observe it. During 1982, dives were longer than in the two previous years (see 'Duration of Dives' section), and we suspect that much water-column feeding was taking place.

Underwater blows, seen with high incidence in 1980 and suspected to be in some way related to feeding (Würsig et al. 1982), were seen only six times in 1982.

Whales tended to be in deeper water in 1982 than in previous years (Richardson et al. 1983a), and it is not surprising that their behaviors and possible feeding appeared different in different ecological situations. Lowry and Burns (1980) found mainly copepods and euphausiids in the stomachs of five bowhead whales taken in early fall from the Beaufort Sea off northeastern Alaska. These invertebrates are known to be abundant at midwater in many areas of the near-shore Beaufort Sea (Griffiths and Buchanan 1982). Although we have no proof, it is probable that whales were feeding on midwater invertebrates in August 1982.

Play Behaviors

Although many social interactions might include play behavior, we can not always distinguish low levels of mating activity or aggression from play. For this reason, we have scored as play behavior only those incidents where whales spent some time at the surface associating with an object other than a conspecific. During 1982, we saw such apparent play behavior performed by one 'non-calf' as it directed its attention at a log for 87.7 min, and by two separate calves as they interacted with a windrow of debris and with water discolored by one of our fluoroscein dye markers. These incidents are described in detail below in the section 'Behaviors Not in Regular Surface/Dive Sequences'.

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 from healed 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 allowed for identification of many individuals.

In the present study, we were often able to identify whales by sight from distinctive chin patch shapes or white marks on the back or tail, and we were thus able to determine dive durations for these individuals. We did not obtain the clear photographs necessary for re-identification of individuals over more than one flight. In 1982, our longest sequence of observations of a single identifiable whale lasted 3.5 h and involved a whale with an extensive chin patch and a small, white spot (about 30 cm diameter) just behind the blowhole. Many other whales were recognized for periods of several minutes to 2 h in a similar manner.

In 1980, two adults and a calf were reidentified about 100 km from the original sighting area two weeks after they were first seen (Würsig et al. 1982). We have no other data on group stability, but such information would be obtainable from a concerted effort to photograph bowhead whales for purposes of individual identification.

Southwell (1899) reported that whalers recognized some bowhead whales in subsequent years in similar areas off Greenland. His report tells us nothing about individuals staying together, however.

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 length of surfacing (surface time) and the length of dive between surfacings (dive time). We will discuss our data on these variables in some detail. Because they 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 the disturbance responses.

The measurement of each of these four quantities depends upon how a surfacing and a dive are defined, so we will first review the definitions and conventions that we used for this analysis. A surfacing was defined as the period of time when a whale is 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; we considered those occasions to be dives if they exceeded an arbitrary minimum of 60 s. Aerial behavior presents certain difficulties for the definition of surfacings and dives. We considered a breach to be an abnormal surfacing of uncertain duration; we excluded breaches from our surfacing analysis. A breach was considered to represent the end of a preceding dive and the start of a subsequent dive. Tail slaps and flipper slaps were not considered to be interruptions of a surfacing if the whale remained in sight. The ability to see a whale just under the surface of the water depends 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 present a special situation. Because of their small size, they are much more difficult to observe than are adults when just under the water's surface. Nursing involves such shallow dives. In 1982, we observed several presumed nursing bouts, and we felt that these merited somewhat different treatment than did the shallow dives of adults. We decided to analyze observations of calves 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 the few obvious subadults (probably yearlings) that we observed. The 1982 results are presented in detail. In addition, we have, for consistency, re-analyzed the 1980-81 data excluding calves, and we summarize those results in the Appendix.

In 1982, we measured the blow interval, number of blows per surfacing, surface time, and dive time for undisturbed non-calves 794, 58, 70, and 51 times, respectively. Figures 4 through 7 present the frequency distributions of these observations. Figures 8 to 11 present the mean value for each of

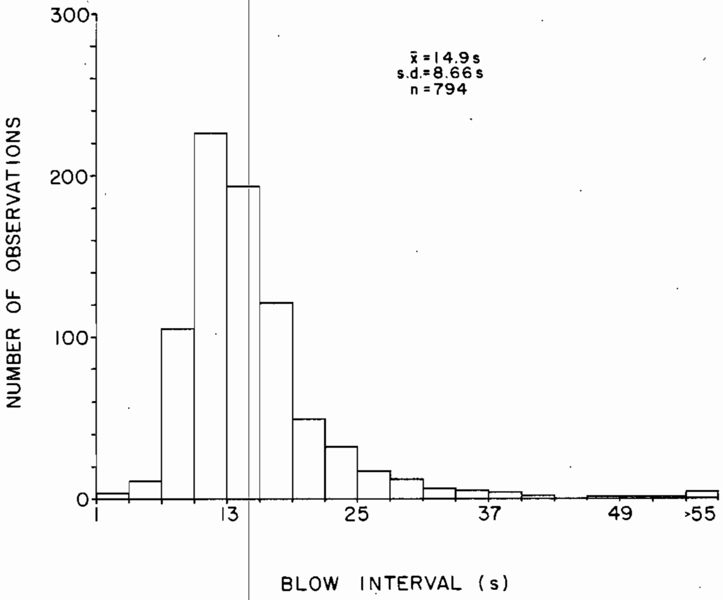

FIGURE 4. Frequency distribution of blow intervals for presumably undisturbed non-calves in 1982.

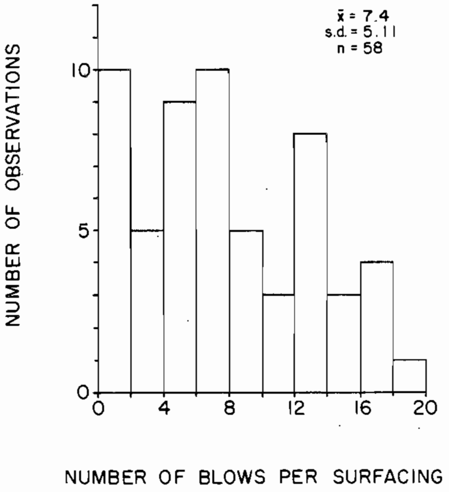

FIGURE 5. Frequency distribution of number of blows per surfacing for presumably undisturbed non-calves in 1982.

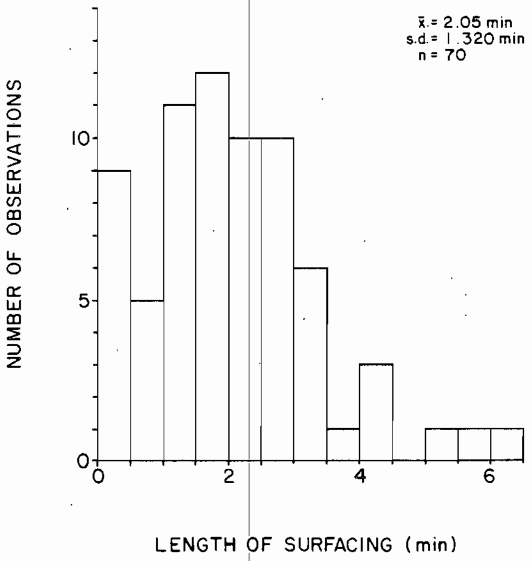

FIGURE 6. Frequency distribution of length of surfacing for presumably undisturbed non-calves in 1982.

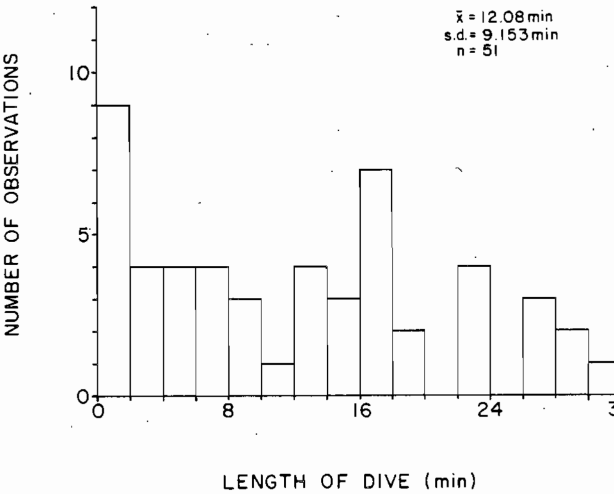

FIGURE 7. Frequency distribution of length of dive for presumably undisturbed non-calves in 1982.

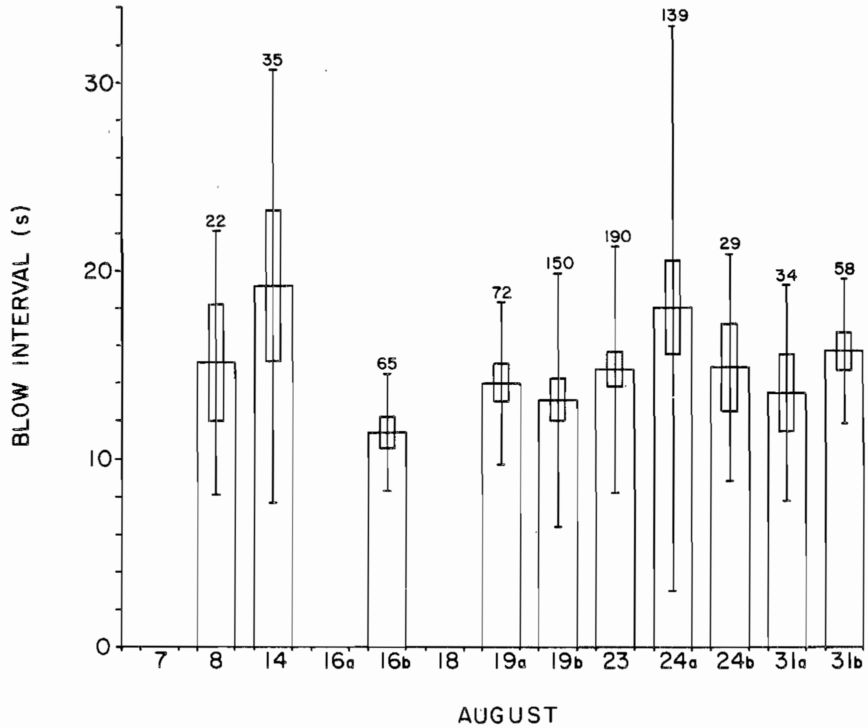

FIGURE 8. Mean interval between blows for presumably undisturbed non-calves during each observation flight in 1982. The vertical line in each column represents one standard deviation on either side of the mean, the box represents the 95% confidence interval for the mean, and the number at the top is the sample size.

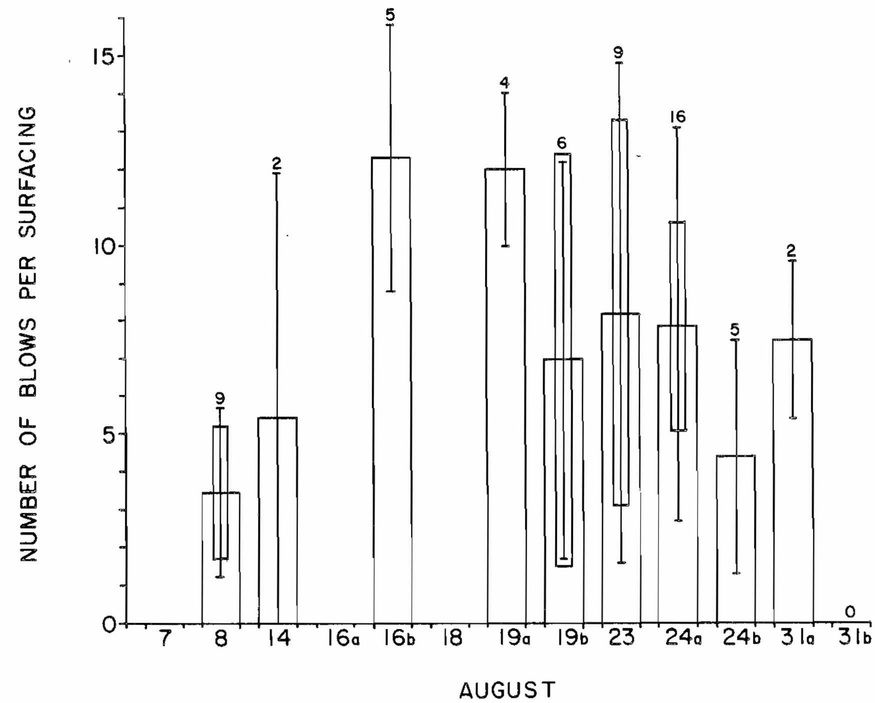

FIGURE 9. Mean number of blows per surfacing for presumably undisturbed non-calves during each observation flight in 1982. Presentation as in Fig. 8.

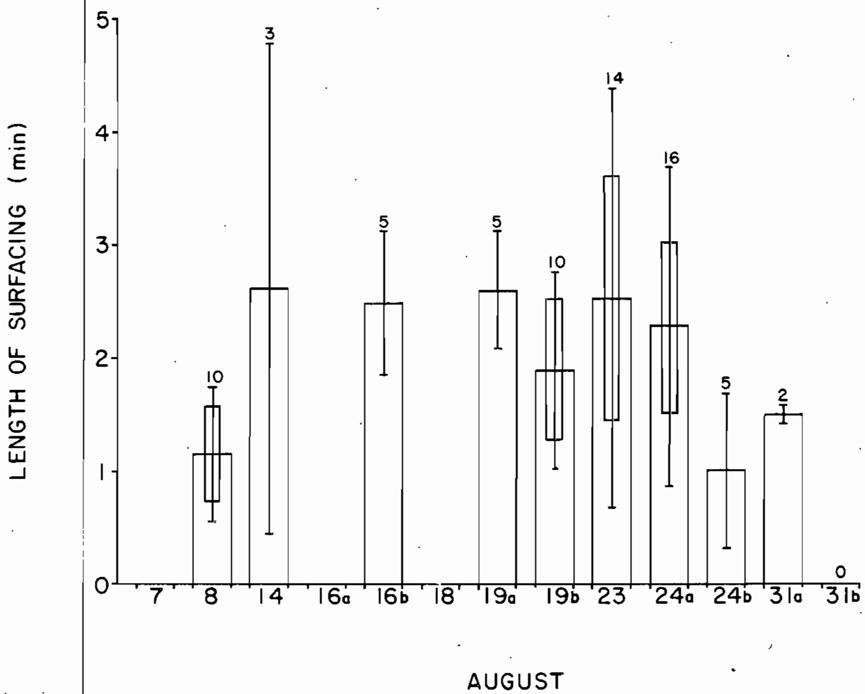

FIGURE 10. Mean length of surfacing for presumably undisturbed non-calves during each observation flight in 1982. Presentation as in Fig. 8.

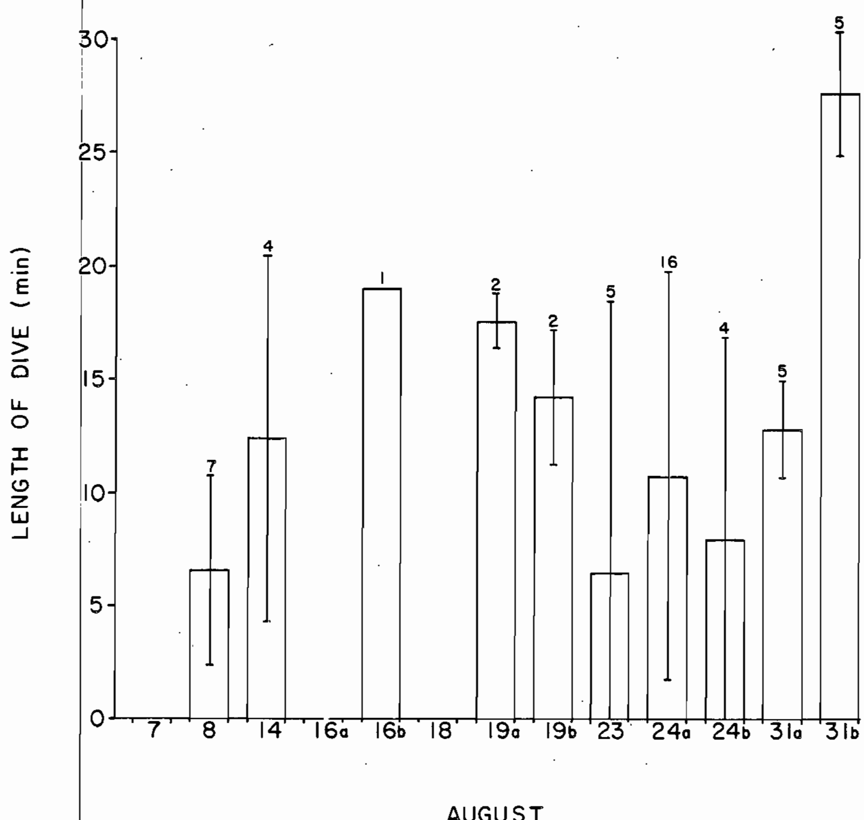

FIGURE 11. Mean length of dive for presumably undisturbed non-calves during each observation flight in 1982. The vertical line in each column represents one standard deviation on either side of the mean, and the number at the top is the sample size.

these four variables during each of our observation flights. Table 3 summarizes each of these variables for 1982.

Blow Interval

As in the two previous years, the interval between blows was the most consistent of the four variables among flights and dates (Fig. 8), and the frequency distribution for blow intervals in 1982 (Fig. 4) was very similar to that obtained in the two previous years (Würsig et al. 1982, Fig. 8). The mean blow interval in 1982, however, was significantly longer for all undisturbed non-calf whales (mean = 14.9 ± s.d. 8.66 s, n = 794, range = 3 to 158 s) than it was among the comparable group of whales from 1980 and 1981 combined (mean = 12.9 ± s.d. 8.32, n = 2028) ($t = 5.52$, $df = 2820$, $p<0.001$).

Blows per Surfacing and Duration of Surfacing

The mean number of blows per surfacing (Fig. 9) and the mean length of surfacing (Fig. 10) in 1982 were more variable among dates than was the mean blow interval. This was also the case in 1980 and 1981. Because of the relative stability of blow intervals, the number of blows per surfacing and the length of surfacing were very highly correlated in 1982 (see Fig. 12), as in previous years. Both of these variables were significantly higher in 1982 than in 1980 and 1981 combined. Thus, while the mean surface time for non-calves in 1980 and 1981 was 1.12 ± s.d. 0.756 min (n = 298), in 1982 it was almost twice that value -- 2.05 ± s.d. 1.320 (n = 70, range = 0.13 to 6.42 min) ($t = 7.84$, $df = 366$, $p<<0.001$). And while the mean number of blows per surfacing for non-calves in 1980 and 1981 combined was 4.3 ± s.d. 2.91 blows (n = 264), in 1982 it was 7.4 ± s.d. 5.11 (n = 58, range = 1 to 19) ($t = 6.25$, $df = 320$, $p<<0.001$).

Duration of Dives

We have previously indicated that our estimates of mean dive duration are biased and are underestimates of the real mean duration (Würsig et al. 1982). The bias occurs because the difficulty in finding and recognizing a whale on re-surfacing increases with increasing length of dive. Long dives are especially difficult to document when numerous whales are in the area.

Table 3. Summary statistics for the principal surfacing, respiration and dive variables in presumably undisturbed bowheads, 1982.

		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		14.9	8.66	794	7.4	5.11	58	2.05	1.320	70	12.08	9.153	51
Calves*		18.6	16.05	100	4.0	2.49	19	1.66	1.459	21	6.82	5.715	29
Adults with calf		18.6	9.46	177	6.4	4.77	20	2.30	1.593	23	8.62	5.862	22
All others (non-calves without calf)		13.8	8.11	617	8.0	5.25	38	1.93	1.164	47	14.70	10.361	29
Socializing whales**		14.2	8.01	74	3.8	2.75	4	1.34	0.796	5	0.58	-	1
Non-socializing whales**		14.9	8.73	720	7.7	5.15	54	2.10	1.341	65	12.31	9.096	50
Depth (m)	16-100**	14.5	5.62	35	3.8	3.13	6	0.86	0.710	6	6.41	8.444	5
	101-250**	13.7	6.67	354	7.7	4.95	25	1.98	0.982	32	13.94	8.143	17
	>250**	15.9	10.18	405	8.0	5.42	27	2.34	1.572	32	11.96	9.679	29

* Surfacings with apparent nursing excluded.
** Calves excluded.

In 1982, conditions for measuring durations of long dives were better than in previous years because often we were circling over only one or two animals and could be certain that we had not missed any surfacings. Thus, the unavoidable sampling bias in favor of shorter dives was weaker in 1982 than in 1980 and 1981. In addition, the whales appeared to be making fewer short dives and more long dives in 1982. These results are apparent in the frequency distribution of dive durations in 1982 (Fig. 7), which is considerably less skewed toward short dives than it was in 1980 and 1981 (cf. Würsig et al. 1982, Fig. 11). However, the distribution shown in Figure 7 is still sufficiently different from a normal distribution to make it necessary again to compare dive times non-parametrically.

The overall mean dive time for non-calves in 1982 was 12.08 $\pm$ s.d. 9.153 min (n = 51, range = 0.13 to 30.98 min), almost four times the value for 1980 and 1981 (3.43 $\pm$ 4.715 min, n = 105). In 1982, 10 of the 51 dives (19.6%) exceeded 20 min in duration; in 1980-81, none of 105 dives were that long. As explained above, we feel that this increase is partly due to a change in the behavior of the animals with respect to previous years and is partly due to better conditions for recording durations of long dives.

Each surfacing of a whale has, of course, a dive before it and a dive after it, and the length of the subsequent dive was strongly correlated with the length of the previous dive (Fig. 13). This indicates that a whale tends to make a series of dives of similar length rather than alternating short and long dives. Both the number of blows per surfacing and the length of surfacing were highly correlated with the length of the preceding dive and also with the length of the subsequent dive (see Figs. 14 to 17). We did not have enough data to determine whether the dive preceding or the dive following a surfacing was more closely related to the length of that surfacing and the number of blows.

<u>Blow Rate</u>

The blow rate, or number of blows per unit of time, was calculated in 1982 as a new quantitative measure of respiration and surfacing. This variable was calculated by dividing the number of blows during a complete surfacing by the sum of the durations of that surfacing and the subsequent

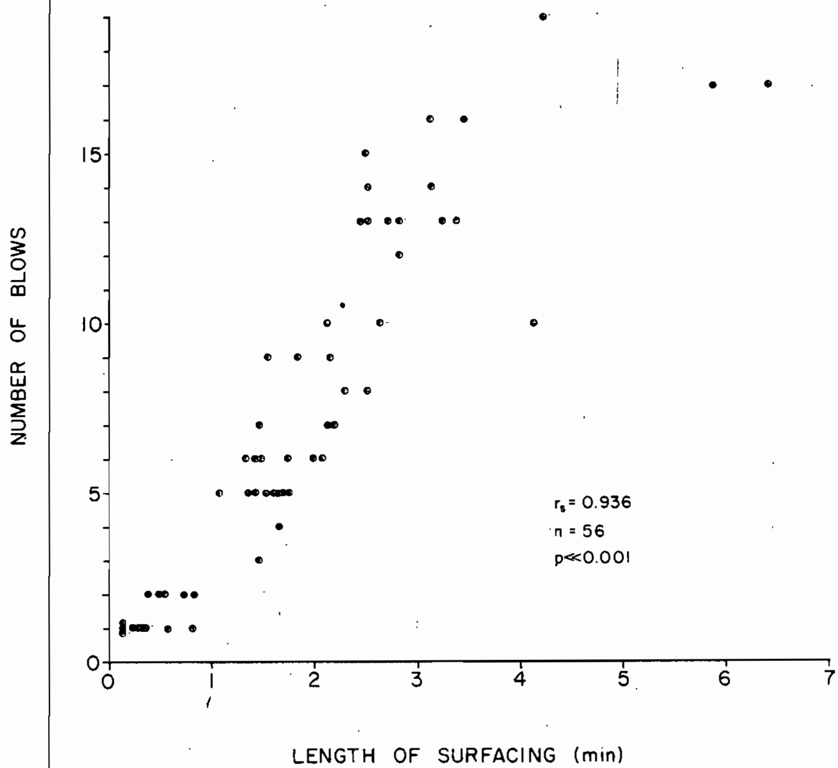

FIGURE 12. Correlation of number of blows per surfacing with length of that surfacing for presumably undisturbed non-calves in 1982. r_s is the Spearman rank correlation coefficient.

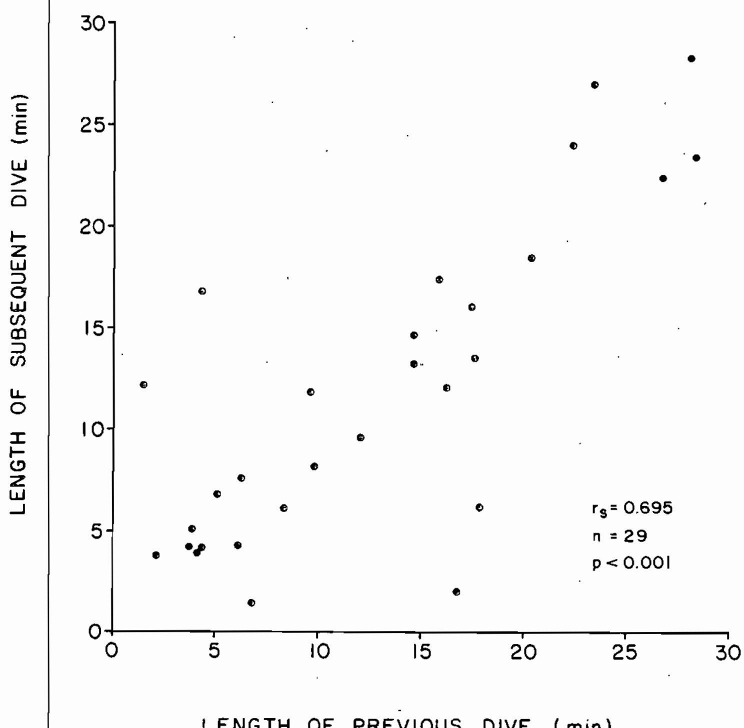

FIGURE 13. Correlation of length of dive subsequent to surfacing with length of dive previous to that surfacing for presumably undisturbed non-calves in 1982. r_s is the Spearman rank correlation coefficient.

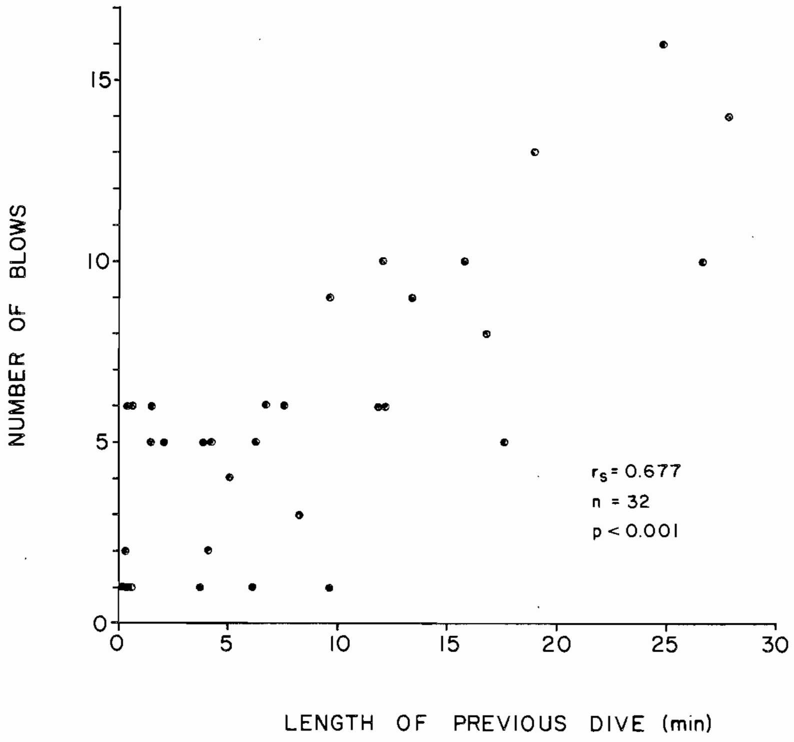

FIGURE 14. Correlation of number of blows per surfacing with length of previous dive for presumably undisturbed non-calves in 1982. r_s is the Spearman rank correlation coefficient.

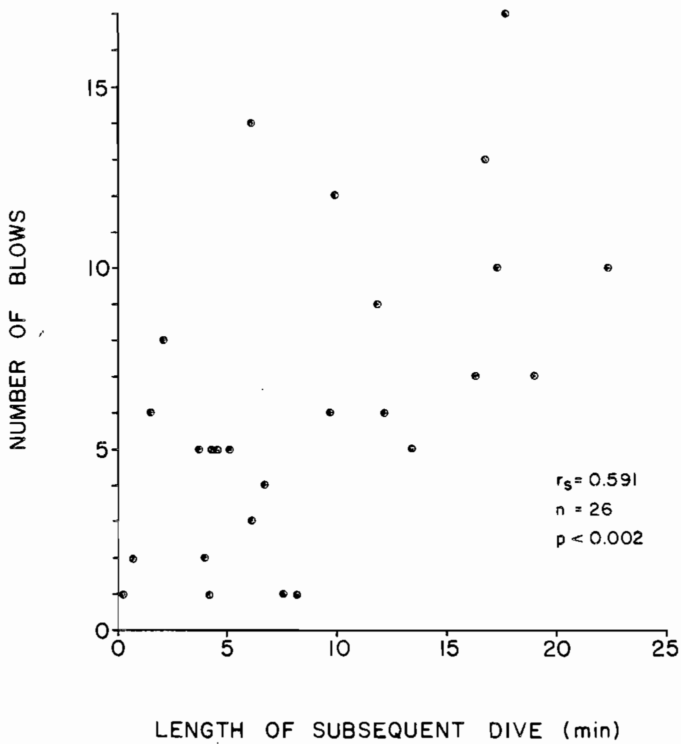

FIGURE 15. Correlation of number of blows per surfacing with length of subsequent dive for presumably undisturbed non-calves in 1982. r_s is the Spearman rank correlation coefficient.

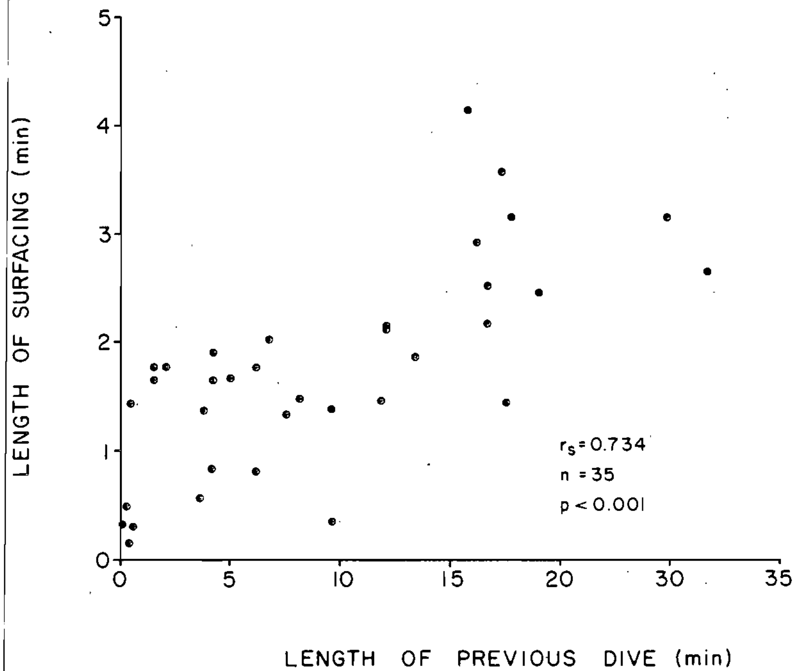

FIGURE 16. Correlation of length of surfacing with length of previous dive for presumably undisturbed non-calves in 1982. r_s is the Spearman rank correlation coefficient.

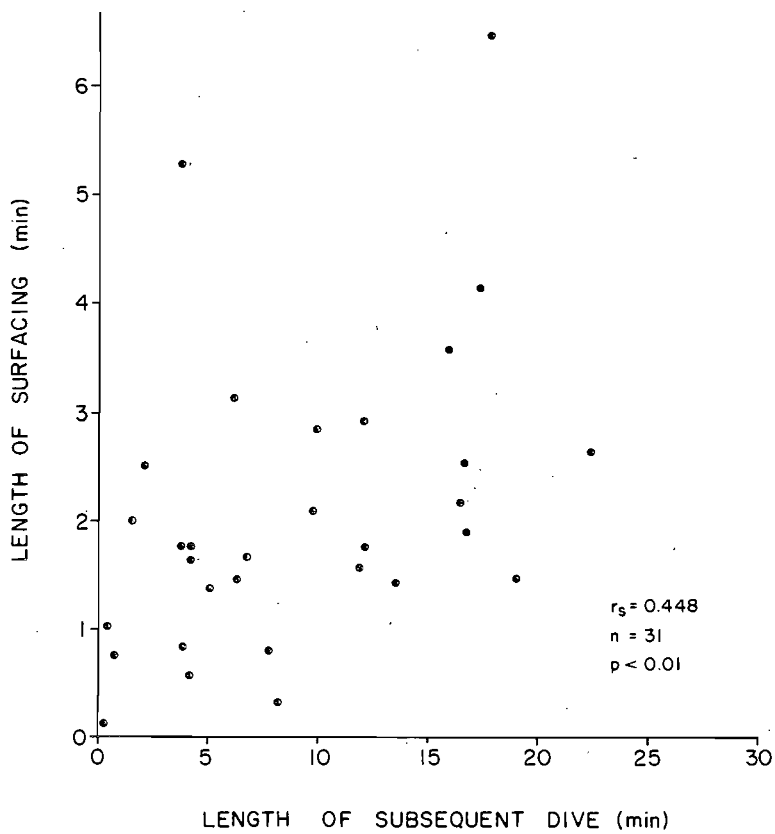

FIGURE 17. Correlation of length of surfacing with length of subsequent dive for presumably undisturbed non-calves in 1982. r_s is the Spearman rank correlation coefficient.

dive*. 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. We suspected that this variable might be especially useful as an indicator of disturbance. Unfortunately, the sample sizes for blow rates are considerably smaller than those for the other variables because blow rate can only be calculated when complete information is available for a surfacing and the subsequent dive.

The mean blow rate for all undisturbed non-calves in 1982 was 0.70 ± s.d. 0.470 blows/min (range = 0.116 to 2.308 blows/min, n = 25 blow rates by 10 whales). In 1980-81, the corresponding mean was 1.28 ± s.d. 1.140 blows/min (range = 0.059-4.364 blows/min, n = 43 blow rates by 22 whales). Figure 18 presents the frequency distributions of these blow rate data. The difference between 1982 and the two previous years was highly significant (t' = 2.93, df = 62, $p<0.01$)**.

Proportion of Time Visible From the Air

Any attempt to determine the number of bowhead whales in an area from aerial census data must incorporate some estimate of the proportion of whales in the area that were visible at the surface at the time of the census. Davis et al. (1982) discuss the considerations involved in making such corrections for census counts. Our repeated measurements of the lengths of surfacings and dives of bowheads allowed us to calculate a related quantity-- the proportion of time that a given whale was visible from the air. We calculated this proportion from all surfacings of known length that were followed by dives of known length for presumably undisturbed bowheads in 1982. For non-calf bowheads, we considered it likely that the whale would still be visible during shallow dives between blows within a surfacing, so we used the measured surface times regardless of such shallow dives. For calves, however, we felt that such shallow dives would probably render the

* Surface-dive cycles in which the dive was <30 s long were excluded from this analysis.

** t' = t-statistic calculated assuming that the two population variances are unequal.

animals undetectable except to observers directly overhead. Therefore, we subtracted from their surface times the estimated length of time that they were slightly below the surface, adding that quantity to their dive times. Short nursing dives were similarly considered to be periods when calves were not visible from the air.

The mean proportion of time that presumably undisturbed non-calves were visible from the air in 1982 was 0.24 $\pm$ s.d. 0.170 (n = 31 surfacing and dive sequences from 13 whales). The comparable value for calves was 0.21 $\pm$ s.d. 0.179 (n = 19 surfacing and dive sequences from 3 calves). Figure 19 presents the frequency distribution for each of these means, which appears to be bi- or multi-modal rather than normal in each case. For the calves, the three highest values came from two instances when calves were separated from their mothers; in one case the calf moved from about 225 m to about 75 m from its mother over two surfacing and dive sequences, and in the second case the calf was probably about 300 m from its mother and was playing in a windrow of debris. The non-calves with the highest values for proportion of time visible, however, did not appear to share any common characteristic.

Depth of Water

To look at the effect of depth of water on the surfacing and respiration characteristics of these whales in 1982, we divided the observations into three depth categories: up to 100 m, 101-250 m, and over 250 m. The results are presented in Table 3. The mean number of blows per surfacing, length of surfacing and length of dive are all lower in the shallowest water and similar in the two deeper water categories. The differences in number of blows per surfacing are of marginal significance both for $\leq$100 m vs. 101-250 m and for $\leq$100 m vs. >250 m (0.05<p<0.10 in both cases). The briefer mean surface time in water $\leq$100 m deep is significant when compared to that for either 101-250 m (t = 2.67, df = 36, p<0.02) or >250 m (t = 2.24, df = 36, p<0.05). The difference in dive time for depths $\leq$100 m vs. all deeper depths is not significant (Mann-Whitney U = 62, n = 5,46, p = 0.1). The relationship between blow interval and depth was non-linear, with intermediate values at $\leq$100 m depth, shortest values at 101-250 m depth, and longest values at

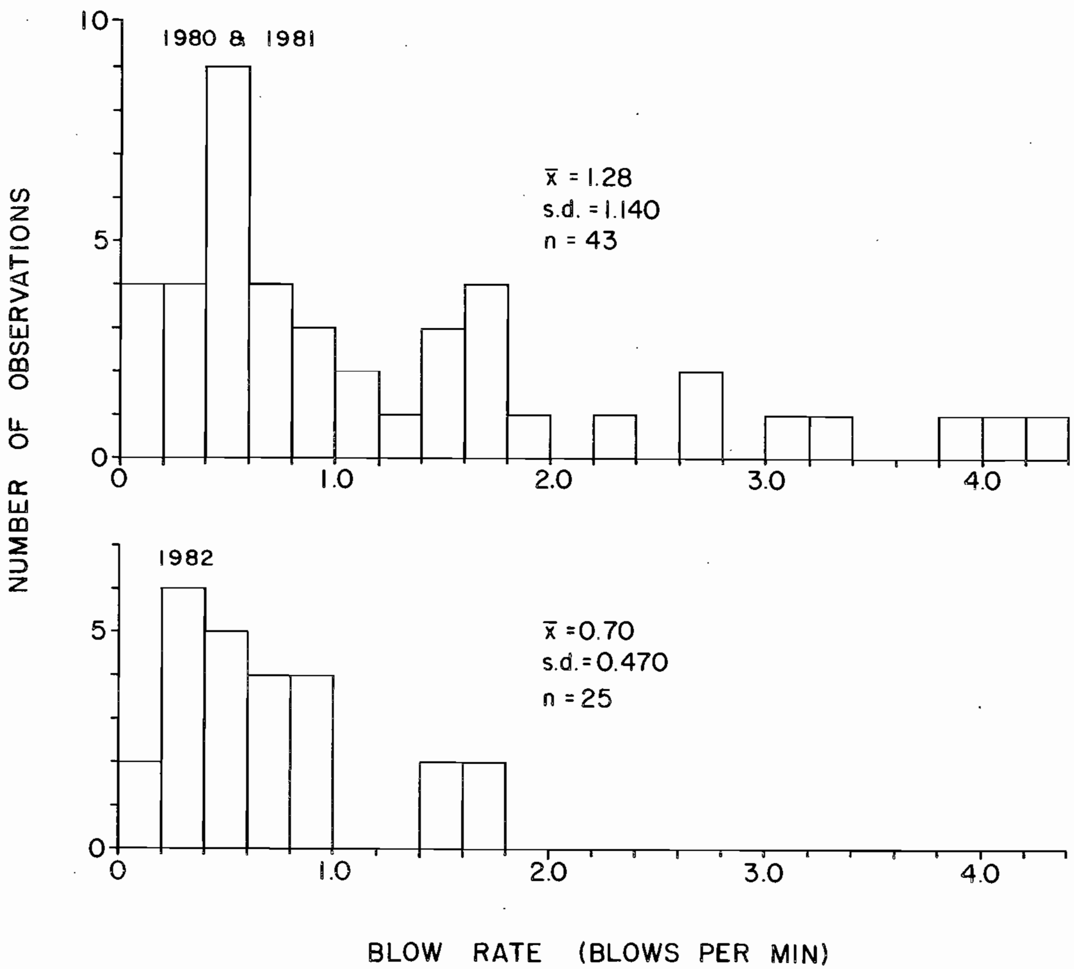

FIGURE 18. Frequency distribution of blow rates of presumably undisturbed non-calves in 1980-81 and 1982.

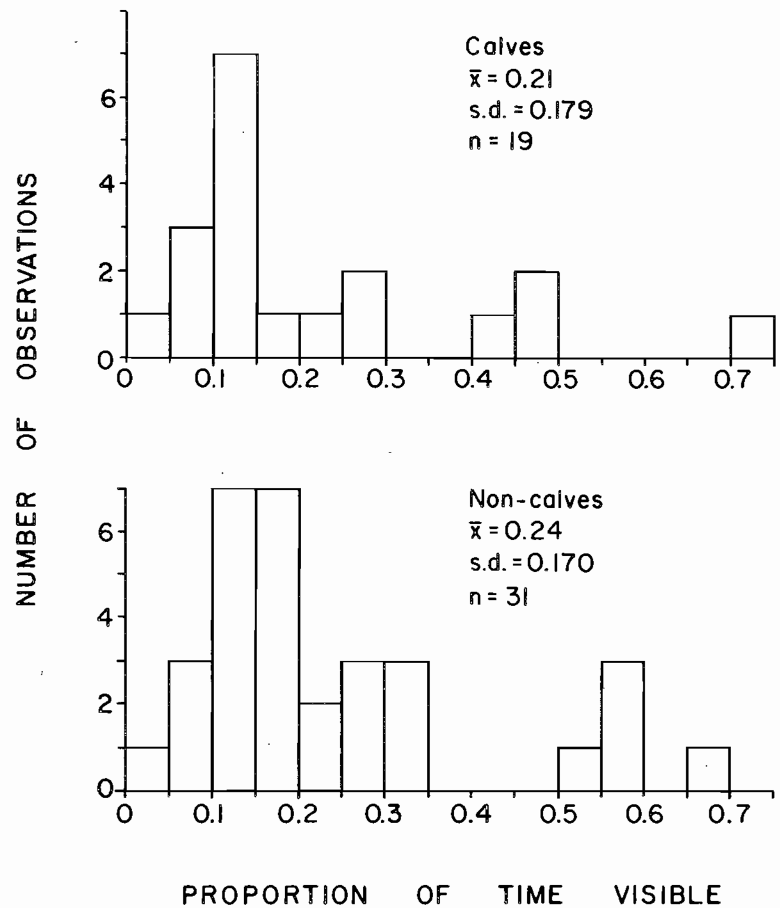

FIGURE 19. Frequency distribution of proportion of time visible from the air for presumably undisturbed calves and non-calves in 1982. The sample size (n) is the number of surfacing and dive sequences, as explained in the text.

>250 m depth (Table 3). The means for the last two categories were significantly different ($t = 3.34$, $df = 757$, $p = 0.001$).

Similarly, the correlation coefficients between water depth and (1) blows per surfacing, (2) length of surfacing, and (3) length of dive were all positive but non- or marginally significant ($r = 0.151$, $r = 0.228$, and $r_s = 0.166$, respectively).

The values of each of the four variables in the shallowest water are much closer to the values for those variables in 1980 and 1981 when whales tended to be in shallower water. This might suggest that the overall increase in these variables observed in 1982 could be attributed at least in part to the occurrence of more whales in deeper water than in previous years.

This suggestion, however, is not supported by the available data. The difference in depth between years was so great that there were almost no observations in water ≤100 m deep in 1982 and even fewer in water >250 m deep in 1980 and 1981. Year-to-year comparisons are possible only for the intermediate depths (101-250 m), and even there the sample sizes are small (Table 4; see also the Appendix). The mean blow intervals in water 101-250 m deep were almost identical in 1980-81 and in 1982, and blow intervals

Table 4. Surfacing, respiration, and dive characteristics for presumably undisturbed non-calves by depth of water in 1980-81 and 1982.

Variable	Year	Depth <100 m	Depth 101-250 m	Depth >250 m
Blow interval (s)	1980-81	12.8 ± 8.10 (1614)	13.3 ± 6.74 (74)	11.5 ± 4.95 (19)
	1982	14.5 ± 5.62 (35)	13.7 ± 6.67 (354)	15.9 ± 10.18 (405)
No. Blows/surfacing	1980-81	4.2 ± 0.80 (209)	4.5 ± 2.66 (11)	- (0)
	1982	3.8 ± 3.13 (6)	7.7 ± 4.95 (25)	8.0 ± 5.42 (27)
Duration of Surfacing (min)	1980-81	1.08 ± 0.700 (240)	1.14 ± 0.537 (11)	- (0)
	1982	0.86 ± 0.710 (6)	1.98 ± 0.982 (32)	2.34 ± 1.572 (32)
Duration of Dive (min)	1980-81	3.97 ± 4.911 (86)	0.50 ± 0.349 (3)	- (0)
	1982	6.41 ± 8.444 (5)	13.94 ± 8.143 (17)	11.96 ± 9.679 (29)

appeared to bear no consistent relationship to depth within or between years. Both the number of blows per surfacing and the duration of surfacing differed significantly between 1980-81 and 1982 in water 101-250 m deep ($t = 2.049$, $df = 34$, $p<0.05$; and $t = 2.698$, $df = 41$, $p<0.02$, respectively). Even this difference must be treated with great caution, however, because all of the 1980-81 observations from water 101-250 m deep came from a single day in 1981. We have observed so much variation in these variables due to factors other than depth, that observations from a single day cannot be considered representative. For duration of dive, the sample sizes at particular depths are too small to allow any comparison between years.

Time of Day

Figures 20 through 23 present the mean values for each of the four respiration, surfacing and dive variables, as recorded in 1982, by time of day. No clear trend is apparent in any of them. This is not surprising, since we did not detect any clear effect of time of day in the previous two years (Würsig et al. 1982, Figs. 18 to 21). A comparison of the mean values before and after 15:00 MDT (sidereal noon) showed no significant difference for any of the four variables.

Calves and Mothers

In 1982, we sighted calves about as often as in the two previous years, considering both the number of observation flights and the number of hours circling over whales. However, the length of time calves were seen at the surface per sighting was considerably higher. Table 5 summarizes the data on calf sightings and surface time for all three years, including both presumably undisturbed and potentially disturbed cases. The length of time that we observed calves at the surface in 1982 was more than three times the observed surface time for calves in either 1980 or 1981. Furthermore, calves accounted for 15% of all whale-hours of observation at the surface in 1982, but only 3% in 1981 and 4% in 1980 (Table 5).

In 1982, calves spent almost 40% of their time at the surface unaccompanied by an adult. This was comparable to their behavior in 1981, but unlike 1980 when they were rarely seen alone (Table 5). As in previous

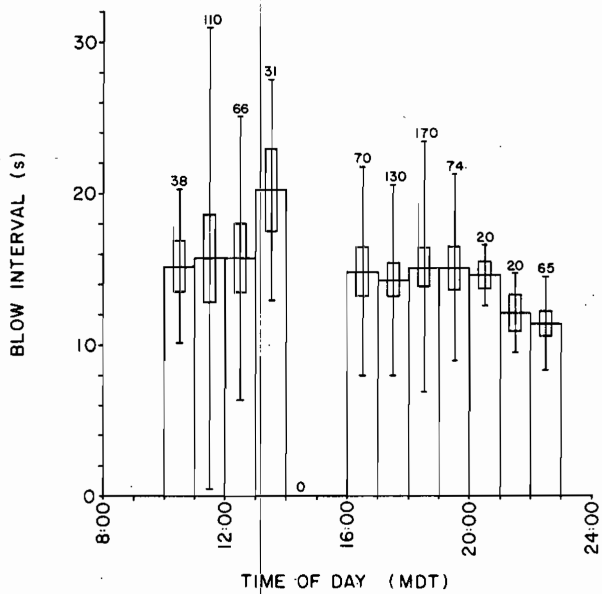

FIGURE 20. Mean interval between blows in relation to time of day for presumably undisturbed non-calves in 1982. Presentation as in Fig. 8.

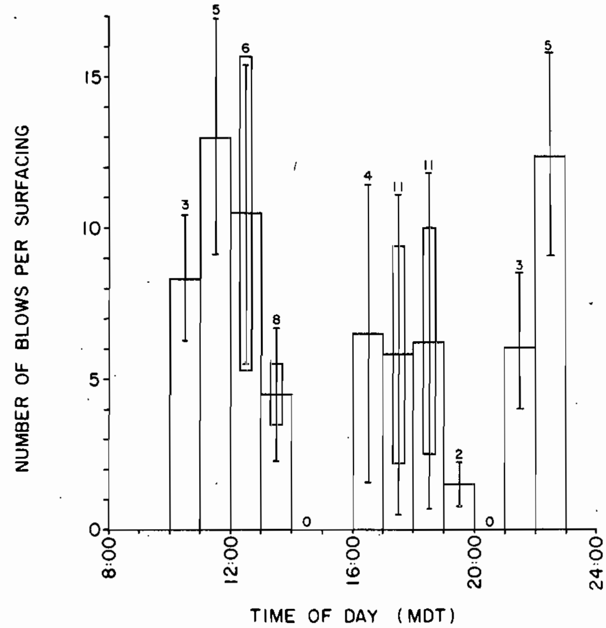

FIGURE 21. Mean number of blows per surfacing in relation to time of day for presumably undisturbed non-calves in 1982. Presentation as in Fig. 8.

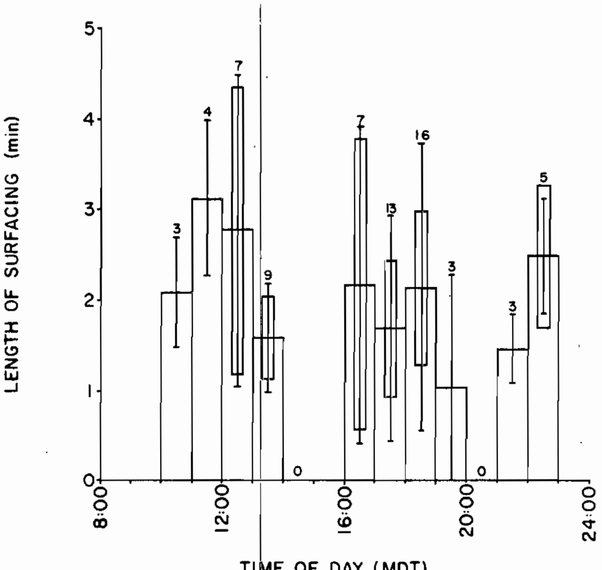

FIGURE 22. Mean length of surfacing in relation to time of day for presumably undisturbed non-calves in 1982. Presentation as in Fig. 8.

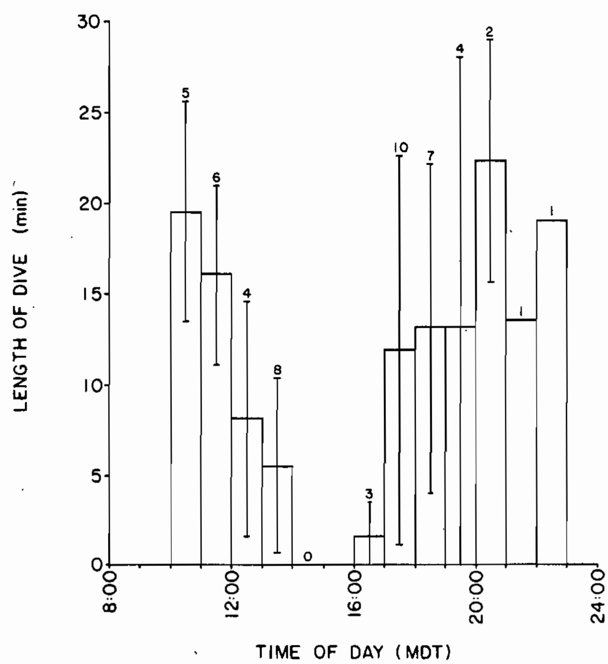

FIGURE 23. Mean length of dive in relation to time of day for presumably undisturbed non-calves in 1982. Presentation as in Fig. 11.

Table 5. Calf sightings and observation time in 1980, 1981, and 1982. 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
No. sightings of calves	12	16	16
No. flights*	14	18	14
Calf sightings per flight	0.86	0.89	1.14
Hours in plane over whales	30.4 h	30.8 h	36.5 h
Calf sightings per hour	0.39	0.52	0.44
Calf time at surface with mother	20.4 min	17.5 min	63.1 min
Calf time at surface alone	1.6 min	12.7 min	38.2 min
Total calf time at surface	22.0 min	30.2 min	101.3 min
% of calf surface time alone	7.3%	42.1%	37.7%
Whale-hours of observation at surface	10.03 h	14.98 h	10.95 h
Calf-hours of observation per whale-hour of observation	0.037	0.034	0.154
Calf time at surface per sighting	1.57 min	1.89 min	6.33 min

* Only flights with behavioral observations considered.

years, when a calf was with its presumed mother, the calf remained within about 10 m of the adult, and occasionally the calf submerged for brief periods oriented toward the teat area of the adult, about half way between the midbody and the tail flukes. These brief submergences probably represented nursing bouts.

Rejoining After Separation

On 18, 19 and 23 August 1982, we observed lone calves at the surface on four occasions, and on three of these occasions we saw the calf rejoin its presumed mother. Since we had observed such rejoining only once previously, from shore in 1981, we will describe each observation in 1982.

On 18 August, a calf was by itself for at least 42 min, mostly at the surface, before it rapidly swam towards an adult and joined it. About 50 min after this, we observed a lone calf 2 to 4 km distant from the original site. After 17 min of observation, it joined an adult by rapidly swimming towards it. We were not able to identify the calf or adult in either case, but in both cases the calf was uncommonly large (about 0.6 adult size). It is probable that the two sightings were of the same calf, left at the surface by the mother during two dives of undetermined length. During the first 18 August incident, the calf oriented straight towards the adult from as far away as 1.6 km. When it came within approximately 75 m of the adult, both calf and adult swam rapidly towards each other. During the second incident, the calf and adult moved toward each other from at least 300 m distance. In both cases, the two dove simultaneously after coming together, with no clear signs of nursing, although we were too far away to see details of behavior in the first instance.

Another lone calf was observed on 19 August, swimming along a windrow of debris and apparently playing with it. We observed the calf for about 18 min and then left without seeing it join an adult. Its behavior is detailed below with other play behaviors observed in 1982.

The final observation of rejoining involved a calf seen on 23 August. This calf appeared to be separated from its mother for at least 71 min. During much of this time, the calf was playing with an area of water discolored by one of our fluoroscein dye markers, and its behavior then is described below with other play behavior. The presumed mother of the calf surfaced about 180 m from it and oriented towards it. When the two were approximately 120 m apart, the calf also oriented towards the adult, but the adult was mainly responsible for closing the distance between them, as it swam at medium speed towards the calf. When the two whales were approximately 22 m apart from each other, the calf dove and reappeared 18 s later, reoriented by 180°, lying to the right of the adult and facing in its direction. The calf then submerged several more times towards the belly of the adult, probably nursing.

Our observations of adults and calves orienting accurately toward each other at some distance suggest that there was some form of acoustic communication between the two. We have possible evidence for this from the last incident described, on 23 August. The rate of low tonal FM calls, which we suspect to be long-distance contact calls, increased while the mother and calf were swimming toward each other from some distance apart and then ceased altogether once the two whales were joined (see 'Bowhead Sounds' below for details). Several unusual higher-pitch calls of undetermined origin were also recorded while the two whales were separated.

Nursing

When the lone calf of 23 August joined its mother after a separation of apparently at least 71 min, we observed the longest probable nursing bout seen during our three summers of observation. We describe it here as an example of this type of behavior. As the two animals approached each other head on, the calf dove out of sight for the first apparent nursing dive when they were still about 22 m apart. The calf dove toward the teat region of the adult six times in all, with submergences lasting 18, 11, 27, 17, 12, and 10 s (mean = 15.8 $\pm$ s.d. 6.37 s). Each of these presumed nursing dives was followed by a brief surfacing by the calf. The surfacings lasted 6, 6, 9, 11, 23, and 17 s (mean = 12.0 $\pm$ s.d. 6.75 s), and each included a single respiration. The nursing ended as the calf and the adult dove out of sight at the same time, and we left the area. While there was no apparent progression in the length of the calf's nursing dives over the entire nursing bout, the calf's surfacings between nursing dives tended to lengthen progressively, suggesting an appeasement of the calf's eagerness to nurse. The duration of the probable nursing bout from the start of the first nursing dive to the start of the deep dive by both mother and calf was 2.78 min.

The other instances of probable nursing observed in 1982 were shorter than the above example, sometimes lasting less than 1 min, and occurred between adult-calf pairs that had not recently been separated as far as we knew. Usually all that we could see was one or two short dives by the calf toward the teat region of the mother at the end of a surfacing sequence, followed immediately by a dive by both animals. On three occasions the calf submerged oriented toward its mother's teat region and did not reappear during a period of just over a minute while the mother remained at the surface, before she too dove out of sight. We do not known whether these three occasions represented continuous nursing for over a minute or whether nursing sometimes occurs when both animals are out of sight below the surface. When calves did resurface after diving toward their mother's teat area, the behavioral pattern was similar to that described for the 23 August calf after rejoining its mother.

Table 6 presents the surfacing, respiration, and dive data collected in 1982 for presumably undisturbed calves during probable nursing bouts, and during non-nursing periods with an adult present and absent. The number of blows per surfacing, length of surfacing, and length of dive were all considerably reduced when calves were nursing. This is simply a quantification of our observation that nursing appears as short dives (alongside the mother) interspersed with short surfacings. Usually calves blew only once per surfacing during nursing bouts, and blow intervals were not determinable. When they did blow more than once per surfacing during nursing, the mean blow interval was shorter than for non-nursing calves accompanied by an adult ($t' = 3.06$, df = 45, $p<0.001$)*. The mean blow rate for calves during their short nursing bouts (which ranged from 51-167 s in duration) was significantly higher than for calves with their mothers but not nursing ($t' = 5.40$, df = 4.5, $p<0.01$). This is probably indicative of the exertion involved in making the nursing dives.

* t' = t-statistic calculated assuming that the two population variances are unequal.

Table 6. Surfacing, dive, and respiration characteristics for presumably undisturbed calves observed in 1982. Numbers presented are mean ± s.d. (n).

Variable	Calf with Mother: Nursing	Calf with Mother: Not nursing	Calf alone
Blow interval (s)	9.7 ± 2.21 (7)	16.1 ± 11.83 (38)	17.6 ± 16.94 (49)
# blows/surfacing	1.3 ± 0.64 (21)	3.6 ± 1.24 (12)	5.5 ± 3.56 (6)
Length of surfacing (min)	0.2 ± 0.12 (16)	1.2 ± 0.50 (13)	2.0 ± 1.50 (6)
Length of dive (min)	0.3 ± 0.09 (16)	6.7 ± 4.63 (13)	2.0 ± 1.15 (6)
Blow rate (blows/min)	2.8 ± 0.93 (5)	0.5 ± 0.28 (10)	1.6 ± 0.23 (4)

For the mother, on the other hand, nursing probably involves reduced exertion, because the mother usually remains stationary while the calf nurses. In the longest example of nursing that we observed, that on 23 August 1982, the mother came to a halt after swimming at medium speed to rejoin her calf. During the calf's nursing dives, the mother lay quietly at or just below the surface. The mean blow interval of the mother reflected this decrease in activity level. It increased from 15.9 ± s.d. 4.46 s (n = 10) while swimming toward the calf to 30.2 ± s.d. 5.12 s (n = 6) while the calf was nursing ($t = 5.88$, $df = 14$, $p<0.001$).

Correlation of Mother and Calf Blow Rates

Nearly continuous observations of an adult/calf pair on 24 August 1982 from 12:17 to 14:00 MDT permitted comparison of the blow rates of the two whales during a variety of activities. The adult was variously engaged in long dives, travel, and apparently providing milk to the calf, while the calf was engaged in shorter dives, travel, and nursing. Figure 24 depicts the relationship between the blow rates of the adult and calf; the correlation between their blow rates is quite strong ($r = 0.87$, $n = 10$, $p = 0.001$). The highest blow rates for the adult occurred following the longest dives, including one occurrence when the adult was being joined by the calf (mean

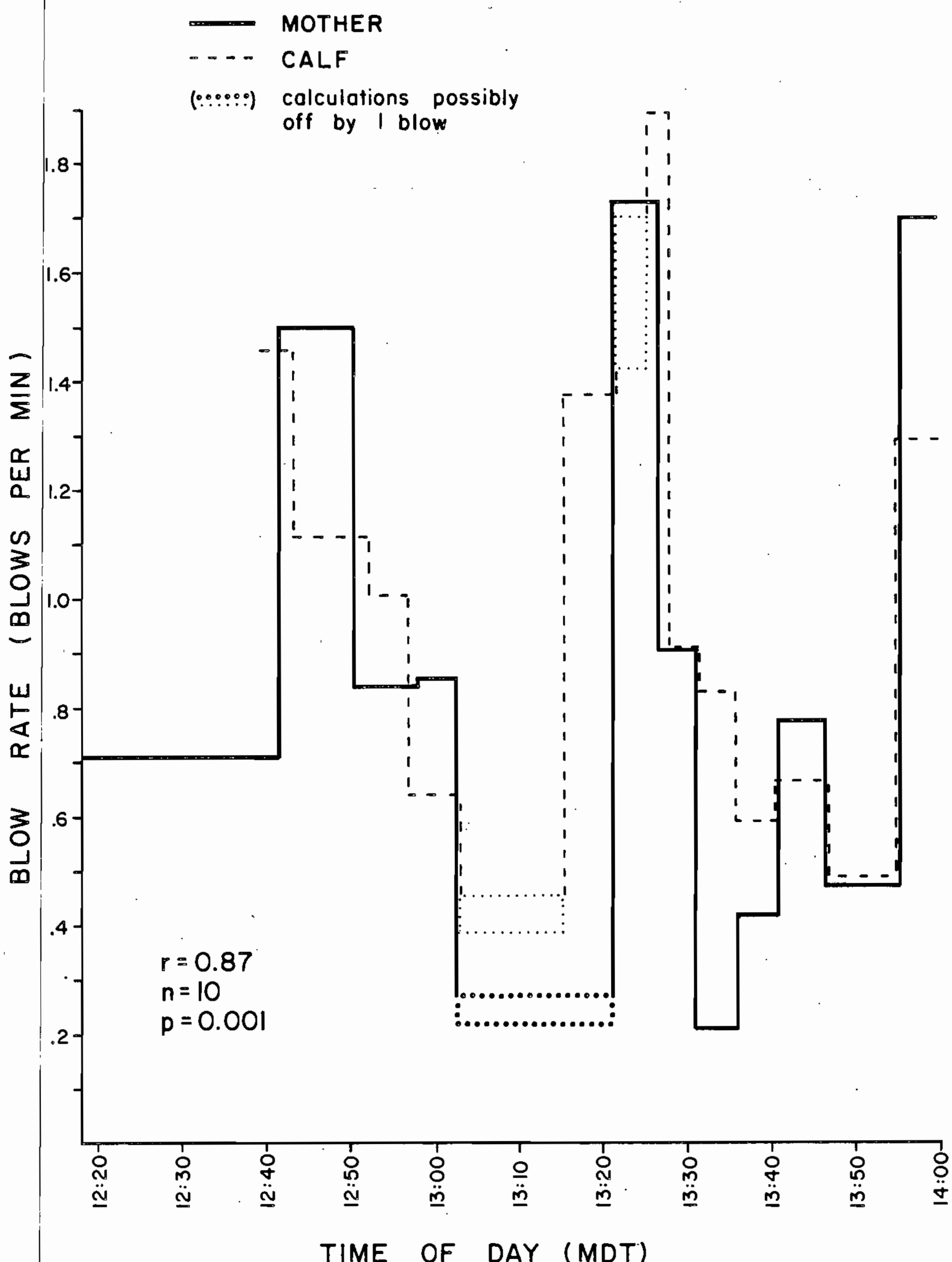

FIGURE 24. Correlation of blow rates between a mother and calf observed for over 1.5 h on 24 August 1982. r is the product-moment correlation coefficient. For the correlation analysis, each blow rate of the mother was paired with the blow rate of the calf that was in effect at the start of the mother's surfacing; blow rates were excluded from this analysis when the number of blows for a surfacing was uncertain.

occurred when the calf was alone at the surface or swimming rapidly towards the adult from as far away as about 225 m (1.58 $\pm$ 0.286 blows/min, n = 3). During surfacing and dive sequences that included nursing, the blow rates for the adult and calf were similar and less than the values given above: adult 1.00 $\pm$ 0.598 blows/min, n = 5; calf 1.04 $\pm$ 0.267, n = 4. The lowest blow rates were observed during travelling: adult 0.59 $\pm$ 0.364 blows/min, n = 6; calf 0.69 $\pm$ 0.176 blows/min, n = 5.

These samples are too small to be anything but suggestive. However, they indicate that measurements of blow rate may be useful in assessing the degree of disturbance to mother-calf pairs from petroleum development activities or other factors.

Calves and Maternal Females Compared with Other Whales

The surfacing, respiration and dive data for adults with calves, calves, and all other whales during presumably undisturbed periods in 1982 are summarized in Table 3 and in Figure 25. Data for calves during surfacings that included nursing are excluded.

Both the maternal females and the calves had longer intervals between blows than did other whales ($t = 6.73$, $df = 792$, $p \ll 0.001$ for maternal females vs. 'other whales'; $t = 4.69$, $df = 715$, $p < 0.001$ for calves vs. 'other whales'). Although the mean blow intervals for mothers and calves were almost identical, the variation in calf blow intervals was much greater. In 1980-81, the mean blow interval for maternal females was also higher than that for 'other whales', but that for calves was not significantly different from that for 'other whales' (Appendix; Würsig et al. 1982).

The length of surfacing did not differ significantly between any two of these three categories of bowheads in 1982, but the mean values were lowest for calves, highest for maternal females, and intermediate for 'other whales'. The same pattern was evident in 1980-81; in those years the mean surface time for calves was significantly less than the mean for either maternal females or 'other whales' (Appendix; Würsig et al. 1982).

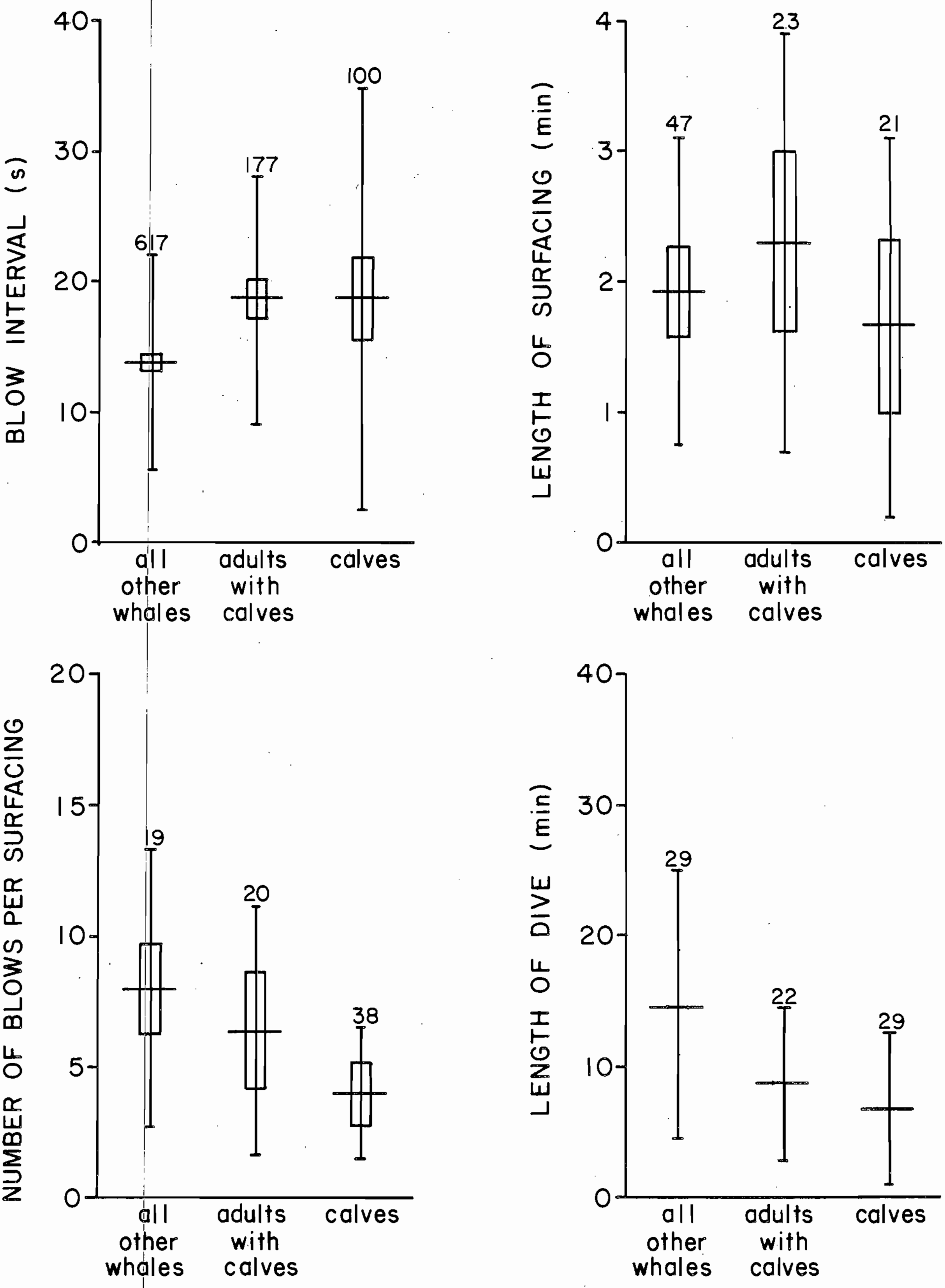

FIGURE 25. Comparison of respiration, surfacing and dive characteristics of calves, adults with calves, and all other whales in 1982. Only presumably undisturbed periods are included.

The number of blows per surfacing was, in 1982, significantly lower for calves than for all other non-maternal whales ($t = 3.14$, $df = 55$, $p<0.001$). This was probably attributable to the increased blow intervals in calves. The pattern of differences between the three categories of whales was the same in 1982 as in 1980-81 (Appendix; Würsig et al. 1982)--lowest for calves, intermediate for maternal females, and highest for 'other whales'. In 1980-81, the mean for calves was significantly lower than the means for maternal females and for 'other whales', and the last two groups did not differ significantly.

In 1982, however, the pattern of dive durations differed from that of previous years. Both mothers and calves dove for considerably shorter lengths of time, on average, than did other whales (Table 3, Fig. 25). The differences in dive times among the three groups were significant (Kruskal-Wallis $H = 6.70$, $df = 2$, $p<0.05$), and dive times for calves were significantly less than those for non-maternal adults (Dunn's multiple comparison, $p<0.05$). In contrast, in 1980-81 the mothers made the longest dives. In both 1982 and 1980-81, calves dove for shorter periods than did any other whales.

The longer blow intervals of the mothers and calves compared to all other whales in 1982, and of the mothers in 1980-81, suggest a lower activity level than in other whales. This interpretation is not supported, however, by the limited data on blow rates for these whales: mothers had a slightly higher mean blow rate in 1982 ($0.714 \pm$ s.d. 0.505 blows/min, $n = 17$) than did the non-calves not accompanied by a calf ($0.659 \pm$ s.d. 0.414 blows/min, $n = 8$). Recent work on mother-calf behavior in southern right whales also found mothers to be relatively inactive (P. Thomas and S. Taber, in prep.; Payne, in prep.).

Social Behavior

Behavior was termed social when whales appeared to be pushing, nudging, or chasing each other or when they were within one-half body length of one another. Interactions between mothers and calves and between whales skim feeding in close proximity were not included as social interactions in this analysis. Whales may, of course, communicate by sound and thus may socialize 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. Our observations of synchronous diving and surfacing over an area many kilometres in diameter (see below) may represent a different form of social interaction from what we discuss in this section. 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 when counting its frequency.

Little socializing was observed in 1982. In presumably undisturbed whales, we observed only seven instances of socializing during three observation flights, on 8, 19 (flight #2) and 23 August. Most whales were alone and making long dives. We calculated the rate of socializing in the three years 1980-82 in two different ways--first, simply based on the number of hours in the plane circling over bowheads (including both surfacing and dive times) and, second, based on the amount of time that whales were visible at the surface. This second procedure involved calculating the number of whale-hours of direct observation (i.e. summing the surface times of all whales observed). Table 7 presents these calculations for each year. Both

Table 7. Rate of socializing among presumably undisturbed bowhead whales, 1980-1982, calculated on two different bases: (1) number of hours circling over whales either above or below the surface, and (2) number of whale-hours of observation, including only surface times of whales.

	1980	1981	1982
A. Number of instances of socializing	42	39	7
B. Hours circling over whales	17.8	17.0	21.8
C. Socializing rate (A/B)	2.4	2.3	0.3
D. Whale-hours of observation	5.9	10.1	6.3
E. Socializing rate (A/D)	7.1	3.9	1.1

methods show a decrease in frequency of socializing in 1982 relative to 1980-81. However, when the number of whales visible at the surface is taken into account, the 1982 decrease is less dramatic, and a progressive decrease in socializing rate over all three years is evident. This progressive decrease may be related to the progressive increase over the three years in the average distance from shore and depth of water for locations where bowheads were studied. However, we found no consistent trend for socializing to occur more often in shallow water in 1982 (Fig. 26) or in either previous year (Würsig et al. 1982, Fig. 27). We had too few observations from shallow water in 1982 and too few from deeper water in the preceding years for meaningful overall comparisons.

Four apparent chases were seen under undisturbed conditions in 1982, with two to four whales about 15 to 45 m apart moving rapidly at the surface, oriented in the same direction with one directly behind the other. One chase observed in 1981 was related to apparent sexual activity, but we saw no evidence of mating in 1982.

During August 1982, there was no indication of a week-to-week trend in frequency of socializing, based on the few data on undisturbed socializing episodes. In both 1980 and 1981, however, more socializing took place in early August than in late August or (in 1981) early September (Würsig et al. 1982). In 1982, all observations of social behavior during undisturbed times were recorded from 16:00-20:00 MDT, somewhat after the peak around sidereal noon (15:00 MDT) found in the preceding two years (Fig. 26).

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 1982 demonstrate this difference:

	Socializing whales	Non-socializing whales
Surfacings with turns	5	35
Surfacings without turns	2	73
Total surfacings	7	108
% surfacings with turns	71%	32%

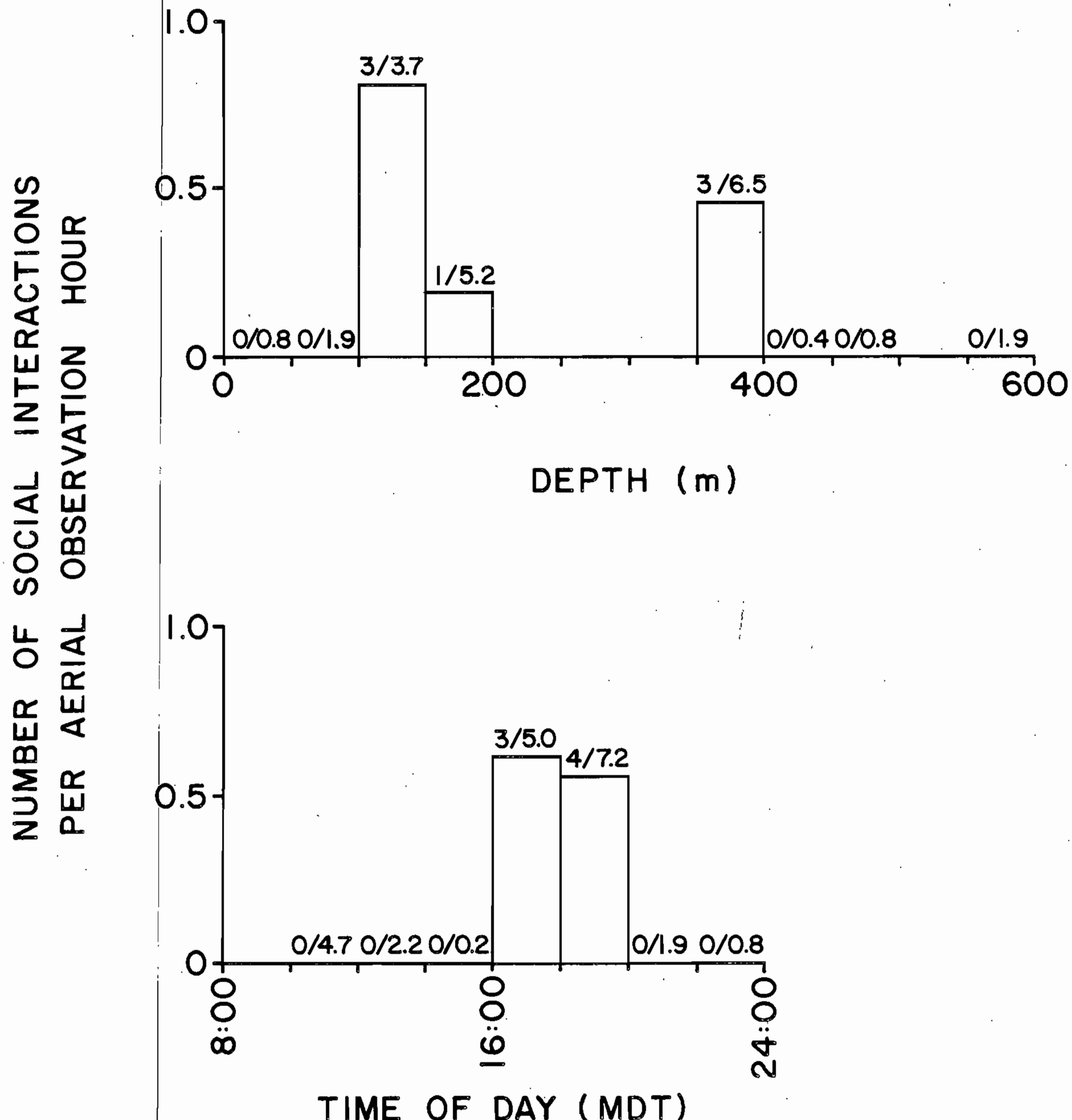

FIGURE 26. Number of observations of socializing per aerial observation hour in relation to depth of water and time of day in 1982 under presumably undisturbed conditions. The numbers at the top of each column are: number of social interactions/number of observation hours.

The socializing whales were significantly more likely to turn than were the non-socializing whales (chi-square = 4.41, df = 1, $p<0.05$), and the same trend is true for the combined 1980-1982 data (chi-square = 7.57, $p<0.01$).

Perhaps because of low sample sizes for socializing whales, none of the respiration and surfacing characteristics differed significantly between socializing and non-socializing whales in 1982. Blow intervals were similar for both categories of whales (see Table 3, t = 0.67, df = 792, p = 0.5). Number of blows per surfacing was higher in non-socializing whales, but the difference was not significant (t = 1.51, df = 56, $0.10<p<0.20$). Mean length of surfacing was also greater in non-socializing whales, but again the difference was not significant (t = 1.26, df = 68, $0.20<p<0.50$). While the mean dive duration for non-socializing whales was 12.31 $\pm$ s.d. 9.096 min (n = 50) in 1982, the one recorded dive duration for a whale scored as socializing was a mere 0.58 min.

The higher values of surface time, number of blows per surfacing, and dive time for non-socializing whales are consistent with the hypothesis that these whales spent much time feeding in the water column. High values of each of these three variables were obtained in 1980-81 during periods of presumed water-column feeding (Appendix; Würsig et al. 1982).

Behaviors not in Regular Surface/Dive Sequences

At times whales behave in a manner different from the usual 'several blows during a relatively short surfacing, followed by dive'. Some forms of apparent play behavior keep whales at the surface for a long period of time, and some 'aerial' behavior--e.g., breaching, tail slapping, or flipper slapping--results in brief but strong disruption of the water surface.

Log Playing

Many logs drift into the Beaufort Sea study area from the Mackenzie River, and during 1981 we observed whales playing with large logs on two occasions (Würsig et al. 1982). In 1982, we witnessed this behavior only once, on 1 August in water approximately 300 m deep. An adult whale was interacting with a log approximately 10 m long for at least the 1.5 h period while we circled overhead. During that period, the seismic exploration vessel 'GSI Mariner' approached from an initial range of about 39 km to a final range of about 24 km. Either distance is close enough for the ship to be a potential source of disturbance (Richardson et al. 1983b), but we will describe the whale's behavior in this section of the report because we feel that this type of play is an interesting if uncommon part of the normal behavioral repertory of bowheads.

Since the whale was with the log both when we first saw it and when we left, we do not know the total duration of the interaction. The whale moved as far as one whale length from the log for only 5 s during the whole observation period, and some part of its body was in contact with the log almost all the time. It lifted one end of the log as far as 2-3 m above the water 30 separate times. Such lifting was done with the head, back, side, or ventrum, and usually lasted for only about 1-2 s. On five occasions the whale rolled the log along its back by gliding under the log while touching the middle of the log with its back. On one occasion, the whale rolled the log while ventrum up beneath it. The whale pushed the log with its head 12 times and with its body while moving against the log sideways 14 times. It clasped the log with either the right or left pectoral flipper eight times. On three additional occasions when the log was perpendicular to the whale's body, it clasped the log under both flippers while ventrum up beneath the log. On eight occasions, the whale placed its chin onto the log and apparently tried to force the log beneath the surface.

All such interactions lasted about 1-10 s. While the whale's orientation to the log changed continually, the whale usually initiated some manner of contact with the log by approaching it head on, that is, perpendicular to the long axis of the log. When the log was pushed by head or back, it moved through the water rapidly enough to create a whitewater wake, and on two occasions the log was propelled for approximately two whale lengths.

The whale was either at or just below the surface almost the entire time, and on only two occasions did it disappear from sight, for 7 s each time. Nevertheless, blows were most frequent during 12 intervals during which the whale was mainly at the surface, with its back slightly above water. The whale blew a total of 43 times during the 1.5 h of observation, for an overall blow rate of 0.48 blows/min. The difference in blow rates between this log-playing whale and all presumably undisturbed non-calves in 1982 (0.70 $\pm$ s.d. 0.470 blows/min, n = 25) is not statistically significant.

The 1982 log play sequence is the longest one described for bowheads to date (cf. Davis et al. 1982, and unpubl.; Würsig et al. 1982). Association with objects other than conspecifics has been described for many marine mammals and for at least four other species of large whales (right whales, Payne 1972; gray whales, Swartz 1977; a humpback whale, Couch 1930; and a sperm whale, Nishiwaki 1962; see also Würsig et al. 1982 for a brief review). Specific elements of the log play that we have observed in bowhead whales are strikingly similar to play with seaweed observed in southern right whales (Payne 1972 and in prep.); both involved lifting the object with the head, moving the object along the back, and patting it with the flippers. The attempt to push the log underwater with the head is also reminiscent of a motion commonly made by male right whales when attempting to mate with uncooperative females (Payne, in prep.). In 1981, one of the log-playing bowheads was also associating with two other whales at the time; in the 1982 example the whale was alone.

Calf Play at the Surface

During the present study, calves were seen alone at the surface on four occasions. Usually they were rather inactive, apparently 'waiting' for their mothers to come up from a dive (see also Würsig et al. 1982). On two occasions, however, lone calves at the surface interacted with debris in the water.

The first such incident occurred over a 12.3 min period on 19 August 1982, when a lone calf, clearly a young-of-the-year, was observed following a windrow, a line of surface debris approximately 2 m wide and probably composed mainly of dead invertebrates. Four minutes before we sighted the calf from the aircraft, an experimental playback of drillship sounds was started from the 'Sequel', which was stationed about 2 km from the calf. When we determined that the animal was a young-of-the-year, we contacted the boat, and the drillship playback was stopped, before the peak playback volume was reached (see 'Disturbance' section of this report for further details). The calf stayed at or just below the surface for the entire period of observation. It oriented directly along the windrow, changing course as the line meandered to the left or right. Although the calf appeared to have its mouth open slightly part of the time, it did not appear to be feeding extensively, if at all, on the line of debris. Its movements along the line thoroughly disrupted the line, however, and the calf left a wake of highly dispersed debris behind it.

The actions of the calf while moving along the windrow were rapid and jerky, reminiscent of any uncoordinated young mammal. The whale calf lunged forward while in the debris on three occasions, and slapped its tail onto the water surface two times as well. It moved rapidly along the line ventrum-up for approximately 30 s, with rapid up and down movements of the tail for the entire time. This energetic behavior is reflected in the very high blow rate of 2.12 blows/min for the 12.3 min of observation. The sequence ended when the calf dove out of sight at the end of the windrow; we did not see it with an adult. We do not believe that this incident represented concerted feeding because the calf's mouth was open only slightly for brief periods. However, in light of the skim feeding that we have observed in adult bowheads at or just under the surface, it is possible that the calf was also practicing skills required for feeding.

A second incident of a calf associating with material in the water occurred on 23 August 1982. This calf was first encountered lying motionless just below the surface or moving slowly forward while almost stationary. During such a slow movement, or perhaps due to current action, it was brought into an area marked by dispersed fluoroscein dye from one of our dye markers (see 'Materials and Methods'). The dye covered an area about 40 m wide and 100 m long. Immediately upon entering the area of bright green water, the calf became active. During the 22.3 min of association with the dye, the calf rolled ventrum up eight times for 5-20 s each time and moved back and forth within and to the edge of the dye/clear water interface. Although not as active and not beating its tail as fast as the calf in the windrow, this calf made abrupt turns of greater than 90° on 25 occasions during its stay in the dye, re-orienting itself at the dye's edge in order to remain within the dye. It blew 27 times during 22.3 min, for a blow rate of 1.21 blows/min.

This was considerably lower than the rate for the more active calf in the windrow, but higher than the mean 0.52 $\pm$ s.d. 0.271 (n = 11) blows/min for calves while they were travelling with their presumed mothers.

Near the end of our observation session, the calf moved out of the dye and oriented toward an adult that was moving rapidly toward the calf. When the two joined, the calf apparently began nursing (see the 'Calves and Mothers' section above).

Aerial Activity

Aerial activity, consisting mainly of breaching, tail slapping and pectoral flipper slapping, occurred sporadically throughout our observation periods. The behaviors are described by Würsig et al. (1982). In 1982, we observed nine bouts of aerial activity, with the average bout lasting only about 20 s. Three lone adults breached 1, 2 and 5 times each; three lone adults and one lone calf (while the presumed mother was below the surface) tail slapped once each. Each of the single tailslaps by adults occurred immediately after the whales lifted their flukes out of the water just before diving. One presumed mother 45 to 60 m from a calf tail slapped 7 times; and another presumed mother slapped with the pectoral flipper 12 times while a calf was approximately 120 m behind her.

Thus, cases of breaching seen in 1982 were performed by lone adults, but observed cases of tail and flipper slapping were often performed by presumed mothers. Both the tail slap bout and the flipper slap bout by presumed mothers took place while the calves were some distance from the adult, and it is possible that the sounds produced by slapping the surface were designed to call the calf to the adult. In the first instance, the calf dove (and may have joined the adult underwater), and in the second instance the calf joined the adult within 10 s of the end of the flipper slapping bout. Similar instances have been described for southern right whales (Payne, in prep.).

The incidence of aerial activity in 1982 was comparable with that of previous years (Table 8). Aerial activity is too infrequent to allow a comparison of presumably undisturbed with potentially disturbed conditions, so all sightings are included in Table 8.

Table 8. Frequency of aerial activity in 1980, 1981, and 1982 based on whale-hours of observation at the surface. Both presumably undisturbed and potentially disturbed periods are included.

	1980	1981	1982
Bouts of aerial activity	6	14	9
Whale-hours of observation	10.03	14.98	10.95
Bouts/whale-hour	0.60	0.93	0.82

Bowhead Sounds

In the last several years there have been several reports documenting bowhead sounds (Ljungblad et al. 1980a, 1982; Clark and Johnson, in prep.; Würsig et al. 1982). Most of these have simply concentrated on describing the whale's sounds, but Würsig et al. (1982) tried to interpret the biological significance of the different sound types by comparing them to the call types of southern right whales, Eubalaena australis (Clark 1982, in press).

In this section we describe the types of bowhead sounds recorded via sonobuoys deployed in the eastern Beaufort Sea during August 1982. The hydrophones were usually 18 m below the surface in water depths ranging from 45 m to 300 m. It is important to note that these depths are considerably greater than those where most sounds were recorded during the 1980 and 1981 studies.

Results from our previous work in 1980-81 indicated that rate of sound production may differ between undisturbed and potentially disturbed conditions. With this in mind, we analyzed all the 1982 recordings to determine rates of sound production. All 30.6 h of sonobuoy tapes were listened to at normal speed while simultaneously being analyzed on a Spectral Dynamics SD301C analyzer. The output of the analyzer was then displayed on a Tektronix 513 memory oscilloscope so that one could hear the sounds and see their spectrographic image at the same time. Using both the visual pattern of the display and an aural judgement (by CWC), each sound was classified as one of the seven previously identified sound types (see Fig. 28 on p. 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 judgement was made as to whether the sound was loud or faint. This entire procedure was done without knowledge of the other behavioral observations during the period of the recording. Aside from presence or absence of industrial sounds on the tapes, CWC also had no specific information about presence of sources of potential industrial disturbance when he classified the bowhead sounds. In order to double check the original tallies, this procedure was repeated for the 16.2 h of recordings which contained high sound rates. In all cases the two sets of counts for all call types and loud sounds were within 3% of the lowest tally.

Table 9 lists the dates and times during which bowhead sounds were recorded in 1982, excluding periods of potential industrial disturbance. Next to each date is a listing of the approximate number of whales within a 3-4 km radius of the sonobuoy (including the number of mother and calf pairs), the general behavior of the animals, the rate of call production expressed as loud calls per whale-hour (calls/wh-h), and a tabulation of the number of sounds of each type. Call numbers are given for loud sounds and for total sounds. Call rate was computed by dividing the number of loud calls by the duration of the recording session and by the number of whales involved. Because the number of whales near the sonobuoy was often difficult to determine exactly, the call rates must be considered as estimates. Faint calls probably were made by whales too far from the sonobuoy to be counted from the aircraft. Blow and slap sounds as well as all faint calls were excluded from the call rate computation.

<u>Blow and Slap Sounds</u>

Compared to the 1980 and 1981 recordings (Würsig et al. 1982), relatively few blow sounds were heard in 1982; the number of slap sounds recorded remained approximately the same. Würsig et al. (1982) noted that the highest numbers of blow sounds were heard when the whales were skim feeding. Although we suspect that whales were feeding out of sight below the surface in 1982, we did not observe any of the skim feeding that was so

Table 9. Daily summary of bowhead sounds recorded during presumably undisturbed periods in 1982. For each period, the upper row of values represents loud sounds and the lower row represents all sounds. Call rate was computed only on the basis of the loud calls because the faint calls were probably made by whales too far from the sonobuoy to be counted from the aircraft.

						# Sounds of Each Type									
						calls								other	
Date	Recording time (MDT)	# of whales	Behavior	Call rate (calls/whale-h)	Whale-hours of recording	Total calls	up	down	constant	double or inflected	high	harmonic	pulsive	blow	slap
8 Aug 1982	17:59–18:55	4 + MC	resting swimming mild soc.	17.5	5.6	98 343	69 147	5 63	20 72	1 19	0 5	0 8	3 29	1 2	0 1
11 Aug 1982	16:31–18:03	1–3	no obs.	0.0	1.5	0 14	0 7	0 6	0 0	0 0	0 1	0 0	0 0	0 0	0 0
14 Aug 1982	17:26–18:08	1	swimming	22.9	0.7	16 205	9 83	0 37	1 29	2 24	0 4	0 11	4 17	0 1	0 0
	18:08–19:00	1 + MC	swimming	6.2	2.6	16 268	3 86	2 65	4 27	1 34	0 22	0 15	6 19	0 0	0 2
16 Aug 1982 Flt #2	21:55–22:47	5–7	swimming	8.3	5.2	43 256	3 87	12 71	2 31	3 19	1 12	5 10	17 26	0 0	0 0
19 Aug 1982 Flt #1	10:49–12:15	5 + MC + MC	swimming, calf play, nursing	3.8	12.9	49 379	9 70	7 79	24 127	3 26	0 7	3 56	3 14	0 0	0 0
19 Aug 1982 Flt #2	16:57–17:16 17:32–19:30	6–8 + MC + MC	nursing? swimming mild soc.	4.0	25.1	100 881	16 287	28 209	18 160	11 50	1 22	17 114	9 39	7 7	0 1
23 Aug 1982	16:36–18:58	8–10 + MC	nursing swimming mild soc.	18.2	26.0	474 1276	80 358	182 376	78 270	75 138	14 56	14 35	31 43	13 13	21 21
24 Aug 1982 Flt #1	11:18–11:59	5–7 (+ MC)	swimming breaching	4.1	4.1	17 297	8 103	0 56	2 27	1 13	1 6	0 4	5 24	0 1	0 4
	12:26–14:24	MC (+ 5–7)	swimming	6.5	15.7	102 498	37 174	15 94	21 92	20 63	3 22	0 4	6 42	0 1	0 6
24 Aug 1982 Flt #2	19:19–20:07	4–5	resting	1.7	3.6	6 310	6 135	0 74	0 56	0 12	0 12	0 16	0 5	0 4	0 0
	20:07–20:46	?	no obs.	3.4	2.9	10 214	2 92	0 22	0 48	0 6	4 23	1 13	3 10	0 0	0 0
31 Aug 1982 Flt #1	10:32–12:08	1	swimming	8.8	1.6	14 163	4 72	0 32	0 43	1 4	1 3	0 0	8 9	0 1	0 0
31 Aug 1982 Flt #2	18:18–19:05	2	swimming resting	0.0	1.6	0 26	0 12	0 2	0 11	0 1	0 0	0 0	0 0	0 0	0 0

MC = mother and calf pair.

apparent in the two previous years. The lack of this form of feeding behavior, coupled with the low numbers of blow sounds, is consistent with our previous evidence that whales feeding at the surface produce more blow sounds than whales engaged in other behaviors.

Call Types

Not including blow and slap sounds, the majority (90%) of sounds recorded in 1982 were tonal, frequency-modulated (FM) 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 1982. Although no quantitative comparisons were made, visual inspection of spectrograms and aural judgement indicated no differences between the general characteristics of sounds recorded in the three summers of 1980, 1981 and 1982.

There was, however, one possible exception. On 23 August 1982, at 18:50 MDT, an unusual sound was recorded which might have come from a bowhead whale. The call occurred during the period when a mother and calf were about to re-unite after being separated (see below for further details). The sound lasted for 5 s and consisted of a broken series of broadband pulses with energy between 2 kHz and 8 kHz. The pulse rate at the beginning of the sound was 16 pulses/s, increased to 28 pulses/s by the middle of the call, continued to increase to a maximum of 44 pulses/s, and then fell to 24 pulses/s at the end. Aurally, this call sounded like a 'twitter'. We note this possible exception to the 1982 bowhead repertoire of calls because the pulse rate is similar to that for some bowhead calls, although the frequency range is higher than previously reported for bowheads. We hesitate to assert that this call came from a bowhead whale because it shares certain characteristics with white whale calls, and there are other calls on the same recording that may have been from distant white whales. It is not possible to determine how close the animal producing this sound was to the hydrophone.

Context of Call Types

The behaviors and contexts observed in 1982 were limited to swimming and long dives, with occasional brief periods of mild activity at the surface.

the calls that southern right whales produce in long-distance contact situations (Clark 1982, in press). We did not record many of the more complex calls that were heard in 1981 in association with bowheads engaged in active socializing and possible mating.

One specific observation regarding sounds and behavior deserves attention. This was the incident on 23 August 1982, discussed in some detail earlier, when a lone calf played in a dye marker and later rejoined its mother and engaged in a long nursing bout. At 18:18 the mother dived and was not seen again until 18:47:40. Between 18:18 and 18:28, when the calf was alone and meandering in the dye patch, 23 loud, low FM calls typical of previously reported bowhead sounds were recorded. Between 18:28 and 18:43 there were only four loud FM calls. Suddenly at 18:44:15 we began hearing loud, low FM calls 1 min after a third, small whale was resighted (18:43:13) at the surface about 400 m from the calf. This small whale moved toward the calf until 18:44:41 when the small whale was seen for the last time about 300 m away. Throughout this approach, the calf did not noticeably react to the small whale. From 18:44:15-18:46:03, 13 loud, low calls were heard. This was followed by 1.5 min (18:46:03-18:47:35) of silence. At 18:47:40, the mother was resighted about 150 m from the calf and was oriented toward it. Within a period of 54 s commencing at 18:47:35, three loud calls were heard. At 18:48:29, the calf turned toward the mother and for the next 2 min, as the mother was swimming in the direction of the calf, there were 12 loud, low calls. The last of these calls came at 18:50:40. The mother and calf were seen together at 18:50:48. From this time until 18:58, when the tape recording ended, no loud calls were heard.

This coincidence between reappearance of the mother at the surface and the production of loud, low FM calls strongly suggests that at least some of the loud sounds were produced by the mother and calf pair. Judging from the intensity of the calls, we feel safe in assuming that they were produced by whales within 1 km of the sonobuoy. From 18:44 to 18:58, the only whales seen within 1 km of the sonobuoy were the mother and calf and the small whale, probably a yearling.

Ljungblad et al. (1980a) recorded two types of sounds in the presence of an adult bowhead and calf: low frequency upsweeps (type A) and harmonically rich calls (type B). Their type A call is quite similar to some of the low tonal FM calls we recorded on 23 August 1982.

For southern right whales, Clark (in press) recorded low frequency upsweeps ('contact calls') from mothers and calves when they became visually separated. The two animals called back and forth several times before reuniting and were silent once they were together again. In contact situations when two adults were involved, Clark also noted that the time between delivery of the contact calls decreased as the whales approached and were about to join each other.

In all these cases, the calls recorded in the presence of calves have not been different from those recorded under similar contexts when only adults were in the area. There is, therefore, no evidence to indicate that calves have calls that are distinct from adult calls (e.g., higher in frequency), with the possible exception of the twittering call of uncertain origin described above. This paucity of information on mother and calf sounds is in part due to the general observation that baleen whale mothers and calves, when together, are quiet (southern right whales--Clark, in press; humpback whales--Tyack 1981; G. Silber, unpubl. data).

Comparison with 1980 and 1981

The most dramatic difference between the 1982 recordings and those for the two previous years was in the rate of sound production. In 1980 and 1981, total call rates from presumably undisturbed bowheads ranged from 0.0 to 30.5 calls/wh-h with overall rates of 2.3 calls/wh-h for 1980 and 3.4 calls/wh-h for 1981 (Würsig et al. 1982). In 1982, if only loud calls are considered, call rates ranged from 0.0 to 22.9 calls/wh-h, and the overall rate for presumably undisturbed whales was 10.2 calls/wh-h. The amount of recording time was greater in 1980 and 1981 than in 1982 (17.6 h vs. 13.0 h, respectively), and the estimated total number of whales near the sonobuoys in 1980-81 was greater than in 1982 (113 vs. 51). The major differences between seasons that might account for this difference in call rate are differences in the behavior of the animals, the increased dispersion between whales, and the greater average water depth at observation sites in 1982.

Compared to previous seasons, we did not observe as much social activity in 1982. We never saw the active socializing that we observed in 1981 when large groups of whales were seen in close proximity to one another rolling, stroking, chasing, etc. (see Würsig et al. 1982, p. 103-111). In 1982, we did occasionally observe brief periods when whales were within half a body length or touching, and we saw a few chases, but none of these activities was as intense or as prolonged as the socializing we observed in 1981. Based upon prior data associating sounds and other behaviors for both bowheads (Würsig et al. 1982) and southern right whales (Clark 1982, in press), we would expect that such a decrease in socializing would result in both a change in the types of sounds produced (away from harmonically rich or complex pulsive types) and a decrease in the total rate of sound production. In fact we observed the former change, but not the latter. In 1980 and 1981, 56% of the calls were harmonically rich or complex pulsive types and 44% were low tonal FM calls, as compared to 10% and 90% in 1982. However, the recorded rate of calling was higher for both of these categories in 1982. This result is counter to what we would have predicted based on the decrease in socializing observed. The greatest increase, by a factor of 16.0, came in the number of low tonal FM calls, while the rate of complex pulsive calls increased by a factor of only 1.5 (these numbers were computed using total number of calls recorded from presumably undisturbed whales, including calls that were not loud). The increase in the number and in the relative frequency of occurrence of low tonal FM calls might be attributed to a second difference between 1982 and the two previous years--increased dispersion between whales in 1982. These low tonal FM calls have the most suitable acoustic characteristics for propagation over long distances, and if, as suggested above, they serve as long-distance contact calls, then whales more widely spaced might have more occasion to produce them.

The third difference in 1982--the greater depths in which most whales were recorded--also seems a plausible, but not a full, explanation for the increase in recorded call rates. During the 17.6 h of recording in 1980 and 1981, there were 291 low tonal FM calls and 208 complex pulsive calls, as compared to 3414 low calls and 228 complex calls during the 13.0 h in 1982. This is a 16.0-fold increase in low calls/h and a 1.5-fold increase in complex calls/h. If one assumes that whales were distributed uniformly, then this would translate into a 4.0-fold increase ($16^{1/2} = 4.0$) in the detection range of the hydrophones for sounds below 300 Hz. For example, if whales were detected within a circle of 4 km radius (50 km^2) in 1980 and 1981 when water depths during recording averaged 33 m, we may have been detecting whales within a circle of 16 km radius (256 km^2) in 1982 when water depths averaged 190 m. These average depths were calculated using the duration of the recording at a given depth as a weighting factor. By the same logic, the detection radius for the higher frequency sounds (above 500 Hz) apparently increased by a factor of 1.2 ($1.5^{1/2} = 1.2$), from 4 km (16 km^2) in 1980 and 1981 to 4.9 km (24 km^2) in 1982. These apparent increases, as related to increasing water depth and sound frequency, are in general agreement with underwater sound propagation considerations. One expects that detection range will increase with increasing depth and that lower frequency sounds will be detectable at greater distances than higher frequency sounds. It is also important to recognize that the low calls have their energy concentrated within a very narrow frequency range such that the instantaneous bandwidth of the signal is on the order of only tens of Hz, while the complex pulsive calls have their acoustic energy distributed across a range of several thousand Hz. These characteristics of the two sound types contribute to their relative differences in detectability.

It appears, then, that the best explanation for the observed increase in recorded calling rate in 1982 is that we were able to detect bowheads farther from the sonobuoys because of increased water depth. Two other factors could have contributed to the observed increase--a real increase in the rate of calling by individual whales, and the possibility that there generally were more whales in the area than were counted during the recording period. We have no direct means of comparing individual calling rates for the three years of observations. There is, however, some evidence that the distribution of whales in 1982 was distinctly different than in the previous two years. In 1982, we usually circled singles or very small groups, whereas in earlier years group sizes were sometimes much greater. The low group sizes in 1982 may have been indicative of greater dispersion of animals, which could help explain the increase in low tonal FM calls. Increased dispersion of animals, combined with an increase in the range of detectability, could also result in an underestimate of the number of whales within the recording area and thus an overestimate of the calling rate per whale.

Whales in Ice

During August 1982, most of the whales seen were in deep water near the continental shelf edge, in a broad line running northeast from Herschel Island (Richardson et al. 1983a). In early August 1982, the edge of the pack ice was generally farther to the north and west, but after mid August the edge of loose brash ice was in the same general area as the main concentration of whales. Whales were frequently seen within 20 km of the ice edge, and we encountered 37 whales within the ice itself. Near these whales ice coverage ranged from less than 1% to about 40%. We cannot compare relative frequencies of whales in ice and out of ice since we biased our flights to search for whales away from ice.

Approximately 75% of the whales encountered in ice in 1982 appeared to hang quiescently at the surface with little activity. This quiescent behavior of whales in ice was also noted in 1981. We cannot compare the activity levels of whales in and out of ice quantitatively because whales in ice are difficult to study, and we rarely circled over these whales for prolonged periods. One lone whale observed for 35.38 min on the evening of 24 August among small loose brash ice dove for 17.6 and 13.5 min and surfaced for 1.4 and 1.9 min. It blew 16 times during the two surfacings, for a mean blow rate of 0.47 blows/min. This is lower than the overall 'undisturbed non-calf' blow rate of 0.70 $\pm$ s.d. 0.470 blows/min (n = 25) for 1982 but not significantly so. More data are needed in order to learn whether such quiescent whales in ice are consistently breathing less often (and are expending less energy) than other whales. Because of the minimal fetch, water surface in areas of partial ice coverage is often extremely flat. In such areas, sea state is often calm even when there are whitecaps in nearby areas of open water. Other whales in calm open-water conditions often appear to rest at the surface (BW, pers. obs.). Thus, the frequent inactivity of bowheads among ice may be related to the low sea state among ice pans.

In 1982, we collected too little information concerning whales among ice to allow meaningful calculation of average surface time, dive time, etc. Such data exist for 1981, and since they have not been reported previously, they are given in Table 10. Durations of surfacing and blow intervals in ice were comparable to those for all undisturbed whales observed in 1981, but number of blows per surfacing and dive durations were appreciably longer for whales in ice.

Table 10. Summary statistics for the principal surfacing, respiration, and dive variables in presumably undisturbed non-calf bowheads in ice and overall, 1981. Overall figures are from the Appendix.

	Situation	Mean	s.d.	n
Blow intervals (s)	Ice	13.2	5.81	72
	All	13.0	8.08	1113
Number of blows per surfacing	Ice	7.6	2.15	7
	All	4.2	2.91	194
Duration of surfacing (min)	Ice	1.26	0.577	12
	All	1.06	0.764	204
Duration of dive (min)	Ice	7.15	2.867	10
	All	3.80	4.986	80

Although most whales encountered in ice during August were quiescent while at the surface, this is not always the case. In 1982, we saw two whales that were moving at moderate speed. In 1981, one whale observed for 69 min was active, with many turns or reorientations, five underwater exhalations, and two defecations. Its mean dive time was 9.14 $\pm$ s.d. 1.468 min (n = 6) and its mean surface time was 1.66 $\pm$ 0.290 min (n = 6). It blew 51 times during the 69 minutes of observation, for a rate of 0.74 blows/min. The defecations indicate that the animal had been feeding recently.

Whales that were moving slowly forward while oriented toward a piece of ice did not turn at the surface in order to avoid the ice, but invariably avoided the ice by diving under it. It appeared that travelling whales they could have diverted around the ice, but we do not have enough such observations to confirm this impression. It is possible that whales diving under large pieces of ice may have done so in response to our aircraft, and that the behavior is not a normal part of the whale's repertoire. However, Carroll and Smithhisler (1980) report that whales migrating among ice also adjust their surfacing and dive regime to the size and location of open water. They dive upon encountering ice (instead of stopping), even though they might not have dived that early had there been no ice. Our observations suggest that a similar situation exists even during slow movement by whales that are not actively migrating.

Synchrony of Behaviors

In 1980, a synchrony in general activity was noticed, with whales doing essentially the same thing (such as skim feeding, possible water-column feeding, socializing, churning up mud in shallow water) in a particular area for approximately five days at a time. In 1981, many whales apparently fed in the water column in deeper water, and some skim feeding and socializing were observed, but no synchronous overall change of behavior was noticed (Würsig et al. 1982). The situation for 1982 was similar to that in 1981. Throughout the one-month study period, many whales dove for long periods. Once again we suspected that much water-column feeding was occurring. Mild bouts of socializing were interspersed throughout August 1982, with no indication of a particular peak in social or other activity.

During 1982, as in the previous two years, we often suspected that there was some degree of synchrony in dives and surfacings by whales as far apart as about 0.5 km from each other. However, we did not gather our data in a way that would allow us to analyze this point quantitatively; instead, we usually concentrated on the behavior of a few 'focal' animals and could not record all other surfacings and dives in the area. Nevertheless, we strongly suspected synchrony in diving and surfacing on many occasions. Possible advantages to synchrony in diving and surfacing might be enhanced communication regarding, perhaps, food and danger. Ljungblad et al. (1980b) also reported synchrony among whales engaged in water-column feeding in an area 75 km east of Kaktovik, Alaska, although those authors also did not treat their data statistically.

Synchrony in surfacings by animals far apart does not necessarily prove that communication is occurring over that distance. The synchrony could be established through independent responses to common external cues. It could also be a result of animals having been close together, and visually synchronized, before observations began; in this case the observed synchrony would be a residual phenomenon that persisted because of whales diving and surfacing for similar lengths of times. None of these possible explanations--acoustic communication, common external cues, or residual phenomenon--can be either proven or discounted at this time.

The occurrence of non-random orientation by widely separated animals may be evidence of a further type of synchrony. During 1981, significant orientations toward a particular direction were found over areas of many square kilometres. We hypothesized that either communication or independent orientation in reference to common physical parameters (such as current) could be responsible (Würsig et al. 1982). In 1982 there were five flights with enough sightings of presumably undisturbed whales for statistical analysis. We took the initial orientation of each whale seen in a given area and subjected the orientations to the Rayleigh test for uniformity (Batschelet 1972); we found no significant orientation. Significant orientations did occur during periods of possible disturbance, however (see 'Disturbance' section, Richardson et al. 1982b).

Interspecific Interactions

As in previous years, no interactions were noticed between bowhead whales and other mammalian species besides humans. Birds, probably attracted to an area of whale activity in search of food, circled briefly over whales on five separate occasions. These were two glaucous gulls (*Larus hyperboreus*), nine arctic terns (*Sterna paradisaea*), three unidentified gulls, and an unidentified bird. Terns and gulls investigated our fluoroscein dye markers several times.

On 16 August, white whales (Delphinapterus leucas) were in the general area of bowheads, but the two species did not come closer than about 0.5 km while they were at the surface. On 19 August, a ringed seal (Phoca hispida) was seen about 100 m from the bowhead whale. White whales often make intense sounds underwater, although at higher frequencies than most bowhead sounds. It is likely that bowhead and white whales knew of each other's presence on several occasions. We do not know what, if any, effect the sounds of one species had on the other.

On 18 August, we encountered a gray whale (Eschrichtius robustus) with muddy water streaming from its mouth, indicative of bottom feeding. The whale was seen at 69°37'N, 138°30'W in an area with approximately six bowhead whales; the gray whale was about 500 m from the closest bowhead, and there was no apparent interaction between them. This was the only gray whale seen during this study in 1982. Three gray whales were seen in the Canadian Beaufort Sea in August 1980 (Rugh and Fraker 1981), and we saw one there in the summer of 1981 (27 July 1981, 71°04'N, 129°37'W).

Year-to-year Variations

From 1980 through 1982 we observed a steady progression in the August distribution of bowhead whales near Tuktoyaktuk from shallow water near shore to deeper water farther from shore (see Richardson et al. 1983a for details). In August 1980 whales came to within 10 km of the coastline along the Tuktoyaktuk Peninsula; in August 1981 whales entered shallow water only for a brief period late in the month; and in 1982 they did not do so at all. We obtained two sightings of bowheads in extremely shallow water (7-9 m) off the Mackenzie River Delta on 18 August 1982, but most whales that were within easy flying range from Tuktoyaktuk were found on or near the continental slope northeast of Herschel Island. In 1980-81 whales were present off Herschel Island in September, but in 1982 they were numerous there as early as mid August.

Such a dramatic difference in distribution over the three years may be due to many different ecological and behavioral factors. A prime consideration may certainly be food supply. The fact that the types and rates of feeding behaviors changed from year to year is consistent with such an explanation. In 1980, whales in shallow water spent much time churning up mud from the bottom, skim feeding at the surface, and possibly water-column feeding in slightly deeper water. In 1981, little mud-churning was seen, and most feeding appeared to be skim feeding and water-column feeding. While we witnessed many defecations in 1980, we saw fewer in the deeper water where whales concentrated in 1981. In 1982, we saw no direct evidence for feeding and only one incident of defecation. However, whales were making longer dives than in either of the two preceding years, and we assume that they were often feeding in the water column out of sight.

Bowhead whales have a very finely fringed baleen which is the longest of any whale species, and they are thus admirably suited for straining small planktonic creatures from the sea. Braham and Krogman (1977) gave evidence that bowheads feed mainly on copepods, amphipods, euphausiids, and pteropods in Alaskan waters. We have found that summering bowheads tend to occur at locations where copepod abundance is above average (Griffiths and Buchanan 1982). Lowry and Burns (1980) examined five whales killed off Barter Island, Alaska, in autumn and found about 60% copepods and about 37% euphausiids in their stomachs. All five whales apparently had fed at least partially near the sea floor; about 3% of the stomach contents consisted of mysids, amphipods, other invertebrates, and fish. Lowry and Burns concluded from stomach content analyses that 'A feeding dive probably involves swimming obliquely from surface to bottom and back, feeding the entire time'.

Although this may be true at times, there is no direct information on underwater feeding behavior. We suspect that the whales can detect concentrations of prey and will open their mouths when appropriate. Durham (1972) also suggested, based on stomach content analyses showing mud-dwelling tunicates, vegetation, silt, and small pebbles, that bowheads feed at times near the bottom. We are left with the overall impression that the bowhead whale is perhaps a more catholic feeder than once thought, capable of taking advantage of many different types of prey items at various locations in the water column. It is unknown whether year-to-year changes in distributions of prey may account for the changes in bowhead distribution that we have observed.

As discussed above, whales were in close proximity to each other less often in 1982 than in the earlier two years. They were thus less often classed as 'socializing' (Table 7). This year-to-year difference in proximity may be related to the difference in type of feeding. While skim feeding at the surface, whales are often in the close echelons described by Würsig et al. (1982), which presumably provide some advantage. The proximity necessary for echelon feeding offers more chance for socializing, and socializing before or after feeding in echelon may be important to that mode of feeding. When whales appear to feed in the water column, however, they usually do not stay as close together as when echelon feeding. Thus, water-column feeding may neither require nor stimulate aggregations of animals, and the suspected predominance of water-column feeding in 1982 may explain the low socializing rate that year. Even when there is no close socializing, however, animals are often in a dispersed group within which acoustic communication is probably possible. Our observations of surfacing and dive synchrony by whales spread over distances of several kilometres indirectly suggest that they may have been in contact by acoustic communication.

Mean values of all four of the principal surfacing, respiration, and dive variables were higher in 1982 than in the previous two years, and this increase was observed both in calves and older whales (see Appendix). As discussed earlier, these increases do not appear to be attributable to the increase in depth, but small sample sizes prevent us from separating depth and year effects. In all three years, the number of blows per surfacing and the length of surfacing were positively correlated because blow intervals were relatively constant.

In 1980, calves at the surface were almost always accompanied by an adult, whereas in 1981 and 1982 calves at the surface were alone about 40% of the time (Table 5). This was presumably due to a difference in the diving behavior of the mothers. In all three years the dives of calves were shorter than those of non-calves, suggesting that calves were not capable of accompanying their mothers on long dives. In 1981, females with calves dove for longer periods than did any other category of whales that year; in 1982, females with calves also made long dives, but not as long as adults without calves (Appendix). The proportion of observation time that involved calves was higher in 1982 than in 1980-81, although the calf sighting rate was similar (Table 5). Blow intervals of females with calves were consistently longer than those of other adults in all three years (see Appendix), perhaps reflecting a lower activity level.

There were no year-to-year differences in the types of bowhead sounds recorded, except for one possible new sound type in 1982, described above. The rate of occurrence of blow sounds decreased considerably in 1982, and the rate of occurrence of calls increased dramatically that year, probably at least in part because of the increase in depths of water frequented by the whales. The relative proportions of various call types also changed in 1982, probably reflecting the lower rate of socializing and the increased dispersion of animals.

Comparison With Other Baleen Whales

Bowhead whales spend their entire lives in arctic and near-arctic waters, apparently never moving far from the ice edge. This habit separates them from all other baleen whales, which may move into temperate or subtropical waters (see, for example, review by Lockyer and Brown 1981). But behavior is in large part determined by feeding mode and related ecological factors (Gould 1982), and here similarities between bowhead whales and several other species are evident.

Gray, bowhead, and right whales are often found in shallow water, and all three species feed on small invertebrates. While gray whales usually feed near the bottom (see for example, Bogoslovskaya et al. 1981), both right and bowhead whales may skim their food at or near the surface (Watkins and Schevill 1976, 1979; Payne in prep., for right whales; Würsig et al. 1982 for bowheads). But all three species are also adaptable in feeding behavior. Gray whales will feed on mysids associated with kelp, for example (Darling 1977), and apparently feed on *Pleuroncodes* sp. in the water column (Norris et al. in press). Right whales also feed below the surface, probably straining swarms of copepods and other small invertebrates in the water column (Pivorunas 1979; Payne in prep.). While it has long been known that bowhead whales feed at the surface and in the water column (Scoresby 1820), it was recently established from stomach content analyses (Durham 1972; Lowry and Burns 1980), and by observing bowhead whales surfacing with muddy water streaming from their mouths (Würsig et al. 1982), that bowheads sometimes feed near the bottom. It is not surprising that we found many similarities in the behavior of these species. Bowhead and right whales, in particular, are morphologically and taxonomically quite similar, and appear to obtain their food in very much the same ways. In fact, Rice (1977), mainly relying on a detailed comparison of morphology of bowhead and right whales, suggested that the two species be put in the same genus, Balaena.

The sleeker rorquals (Balaenopterid whales) generally gather their food more actively by lunging through concentrations of prey, and at least in the case of humpback whales, have developed complicated behavioral strategies for confining and concentrating their prey (Jurasz and Jurasz 1979; Hain et al. 1981). The behavior of rorquals in general appears to be less similar to that of the bowhead whale than its behavior is to that of gray and right whales.

Gray whales spend part of the winter in warm water, near the shores of Baja California, and most of the summer they feed in the northern Bering and southern Chukchi seas. Western Arctic bowheads make much shorter migrations, spending their winters in the pack ice of the Bering Sea, and their summers predominantly in the Beaufort Sea. The two species thus use the Bering Sea at different seasons--gray whales to feed in summer and bowhead whales apparently to mate and calve in winter. In addition, the summer and autumn habitats overlap in part. Both gray whales and bowhead whales feed in the lower Chukchi Sea in autumn, and in the 19th century bowheads as well as gray whales occurred there in summer (Townsend 1935; Dahlheim et al. 1980). We have seen a single gray whale in the Canadian Beaufort Sea during each of our three years of bowhead whale work, but this represents the outer fringe of the gray whale's summer range (Rugh and Fraker 1981).

Like bowhead whales summering in the Beaufort Sea, the primary activity of gray whales summering in the Bering Sea is feeding. However, both bowheads (Würsig et al. 1982) and gray whales (Sauer 1963; Fay 1963) occasionally socialize during summer. The blow rate of gray whales feeding near St. Lawrence Island in July 1982 was similar to, although slightly higher than, the blow rate of non-calf bowhead whales in August 1982 (gray whale mean = 0.93 $\pm$ s.d. 0.229 blows/min, n = 67 whales; bowhead whale mean = 0.75 $\pm$ 0.581 blows/min, n = 24 blow rates by 10 whales; gray whale data from Würsig et al. 1983). This is of interest because the whales were in each case mainly engaged in feeding. The higher respiration rate in gray whales may have to do with an inherent increased metabolic rate over that of bowhead whales, perhaps since gray whales are of smaller size than bowhead whales. The basic pattern of diving for several minutes and then surfacing, generally for 4-10 respirations, is also similar for the two species on their summer feeding grounds.

The close similarities in behavior and vocalizations between right and bowhead whales have been summarized by Würsig et al. (1982). We here add further examples of similarities based on observations of southern right whales (cf. Payne in prep.).

Right whales, like bowhead whales, often appear to feed in the water column and to stay in the same general area for days. Right whales, like bowheads, also skim feed at the surface (also described by Watkins and Schevill 1976, 1979), and while skim feeding they at times aggregate into echelons. In right whales, these echelons usually consist of only 3 to 6 whales, while up to 14 bowhead whales have been seen (in 1981) skim feeding in echelon. However, Payne's observations of right whales have been obtained during the winter when little feeding occurs, and differences in feeding details may be due to seasonal factors. The same argument may hold for social activity. While the same kinds of nudges and pushes have been observed for interacting whales of both species, the winter-spring social activity of right whales is much more boisterous than the summer social activity of bowheads. Observations of bowhead whales in spring indicate that their social-sexual activity at that season can be every bit as boisterous as is seen in mating groups of right whales (Everitt and Krogman 1979; Carroll and Smithhisler 1980; Rugh and Cubbage 1980; Johnson et al. 1981; Ljungblad 1981). The belly-up position of a female bowhead photographed in spring in the Alaskan Beaufort (Everitt and Krogman 1979) indicates that females may attempt to evade potential mates who pursue them in large mating aggregations in the same way that female right whales evade males in Argentine waters (Payne in prep.). A photograph showing a remarkably similar mating group of right whales is shown in Payne (1976). The fact that similar-looking social aggregations are seen in both species argues for a similar social system, although it does not show that the social systems are similar in all details.

Payne (in prep.) recently found that most female right whales have young only at intervals of three years or more. This unexpectedly long calving interval may help to explain why the right whale has not made as dramatic a recovery from commercial exploitation as has, for example, the gray whale. Payne also discovered that the right whale females that calve in his study area along the shore of southern Argentina in winter are usually not present in the years between calving. Each winter, a different segment of the population of mature females is present, in a 3-yr cycle. It is not known whether this cycling extends to the summer feeding grounds of these right whales. Although there is no information on the calving interval of bowhead whales, a long calving interval, similar to that of right whales, may be one explanation for their slow recovery rate. This raises the possibility that some kind of cycle may be present in bowhead whales as well. During the present three year study, year-to-year variation in feeding and social behavior was dramatic, but we do not know whether this was due in part to some cyclic and synchronized activity of individual whales, or whether the differences were the result of overall non-cyclic differences in distribution and abundance. Recent efforts to develop a catalog of individually recognizable bowheads (Davis et al. 1982, 1983; D.K. Ljungblad, unpubl.) should provide the basis for studies of the behavior and reproductive history of individual animals. Such work should ultimately shed light on possible long-term cyclical patterns, and will help us to ascertain the relative importance of particular areas to the biology of bowhead whales.

Comparisons with Bowhead Whales During Migration

In the Beaufort Sea in summer, the predominant activity of bowhead whales appears to be feeding. We suggest that this generalization is not contradicted by the paucity of direct observations of feeding during August 1982; instead we interpret our 1982 observations as indicative of a shift in the type of feeding to predominantly water-column feeding in deep water.

From 1980 through 1982, we observed dramatic variations in the type of feeding both from year to year and from place to place within one year. In addition to variable amounts and kinds of feeding, the bowheads in the Beaufort Sea in summer engage in variable amounts of social activity and aerial behavior; they do some travelling from place to place; and the young-of-the-year are still apparently nursing, but spend variable amounts of time separated from their mothers.

During both spring and fall migration into and out of the Beaufort Sea, bowhead whales probably engage in all of the behaviors observed on the summering grounds, but with different relative frequencies. Thus, while travelling is the predominant activity during migration, socializing and mating also occur, more often in spring than in summer or fall; feeding has been reported both in fall and, rarely, in spring; aerial activity occurs at least in spring; and young-of-the-year are closely associated with their mothers, probably nursing. We will review the evidence for each of these types of activity in turn.

During spring migration, bowhead whales appear to do little feeding before they reach the Canadian Beaufort Sea. Bowheads taken in Alaskan waters in spring usually have nearly empty stomachs (see Marquette et al. 1982 for review). Some, however, do contain food, and it seems likely that the amount of feeding during spring migration increases as whales approach the summer feeding grounds.

Bowheads seen off northern Alaska in September as well as October have usually been described as migrating, but it is becoming clear that many of these animals are feeding, loitering, and exhibiting behavior very similar to that seen in the Canadian Beaufort Sea in summer. Bowheads may loiter for considerable periods in the eastern portion of the Alaskan Beaufort Sea during late August and September, and considerable feeding occurs at these times between Kaktovik, Alaska, and the Alaska-Yukon border (Ljungblad et al. 1980b; Lowry and Burns 1980; Ljungblad 1981 and pers. comm.). Bowheads seen in this area in late August and early-mid September typically dive repeatedly in the same locations, and do not begin to travel rapidly westward until later in September. All 10 bowheads killed and examined near Kaktovik in autumn had been feeding recently, mainly on copepods and euphausiids (Lowry and Burns 1980; Marquette et al. 1982; L. Lowry and T. Albert, pers. comm.). These observations suggest that the eastern part of the Alaskan Beaufort is a part of the main summer feeding range. Bowheads encountered there before mid September are likely to behave in a manner very similar to the behavior of bowheads feeding somewhat farther east in the Canadian Beaufort. Since their 'normal' behavior is similar, it is probable that their reactions to sources of potential disturbance will also be similar.

Later in autumn, bowheads tend to travel more consistently and rapidly toward the west. However, feeding has also been reported just east of Point Barrow during several autumns, and also off the Soviet coast (e.g., Braham and Krogman 1977; Braham et al. 1977; Lowry et al. 1978; Johnson et al. 1981; Marquette et al. 1982). The rate and consistency of feeding during fall migration probably is lower than in summer, but quantitative data for comparison are lacking.

The primary mating period of bowhead whales occurs in early spring and appears to include the spring migration (Everitt and Krogman 1979; Carroll and Smithhisler 1980; Johnson et al. 1981; Ljungblad 1981). Everitt and Krogman (1979) described a particularly active mating group of six whales seen on 8 May 1976 near Point Barrow, Alaska. We saw some evidence for mating in the Canadian Beaufort Sea both in 1980 and 1981, but not in 1982. Even the active rolling at the surface that we observed in 1981, however, was not as boisterously active as the large mating group described by Everitt and Krogman. Mating probably is more common during spring migration than during summer in the Beaufort Sea. Non-mating social activity, detailed in this and previous reports, also appears to be more common during the spring migration, but quantitative data for spring are lacking. The summer-to-summer variability in frequency and type of socializing that we have found may be due in part to variability in type of feeding, as was discussed previously. During the August-early September 1981 period, there was an indication of less social interaction later in the period (Würsig et al. 1982). This apparent waning in social activity may be a continuation of the waning of sexual activity that started in late spring. Detailed behavioral observations of bowheads during fall migration have not been reported, so we do not know whether socializing and mating occur during that season.

Aerial activity similar to what we have observed in the eastern Beaufort Sea--breaches, tail slaps, pectoral flipper slaps, and rolls--has been observed in bowheads during spring migration (Carroll and Smithhisler 1980; Rugh and Cubbage 1980). In addition, Carroll and Smithhisler reported spy hopping, which we have not observed. Rugh and Cubbage recorded breaches in 23% of 280 bowheads observed in 1978 from Cape Lisburne, Alaska, a rate far above what we observed, but also higher than the reports from other spring observation sites. Although quantitative comparisons are not possible among the various observation sites, our impression is that aerial behavior is more frequent during spring migration than on the summer feeding grounds. This is consistent with the fact that Rugh and Cubbage (1980) observed the rate of breaching to decline through the spring season. Behavioral observations during fall migration have been too limited to allow comparison.

Travelling is clearly more pronounced in spring and late autumn than in summer but bowheads sometimes move long distances within the July-early September period. Carroll and Smithhisler (1980) estimated that 95% of the time that bowheads were observed migrating past Point Barrow and Point Hope in the spring, from 1975 through 1978, the animals 'exhibited the normally expected migratory surfacing patterns', i.e. were travelling. Similarly, Davis and Koski (1980) and Koski and Davis (1980) found that Eastern Arctic bowheads migrating along the coast of Baffin Island in fall travelled consistently to the southeast. Ljungblad (pers. comm.) has found that after a certain date in late September, varying from year to year, most bowheads seen in the Alaskan Beaufort Sea are oriented westward, whereas before that date most are feeding and loitering. We have no estimate for the percent of time that bowheads summering in the eastern Beaufort Sea were actively travelling; it was low but not zero. In 1982, whales often appeared to be travelling, more often than in previous years and sometimes rapidly (Table 1). However, we usually could not be sure that these whales were travelling as we watched them, because slow travel with long dives is difficult to distinguish from what we consider to be water-column feeding. Although direct observations of rapid travel during summer were infrequent, changes in distribution from week to week and month to month provided proof that large numbers of whales often do travel long distances within the eastern Beaufort Sea and Amundsen Gulf during summer (Renaud and Davis 1981; Davis et al. 1982; see Richardson et al. 1983a in this report).

Because the predominant activity of bowheads during spring and late fall is travelling, their surfacing pattern is slightly different from that usually seen in summer, as mentioned earlier. During the intervals between blows within a surfacing sequence, migrating bowheads usually make brief shallow dives often called 'series' dives (Rugh and Cubbage 1980), perhaps because of the hydrodynamic advantage for a moving whale to avoid the air-water interface. Summering bowheads, on the other hand, often remain at the surface between blows, probably because it is easier to breathe if the whale remains at the surface and because submerging provides no hydrodynamic advantage if the whale is not trying to make forward progress.

The behavior of bowhead calves during migration has not been described, and nursing has not been reported, so we cannot compare calf behavior in different seasons. Most calves are apparently born in winter or spring before the whales reach Point Barrow; nursing presumably occurs during spring migration. Davis and Koski (1980) reported detecting young-of-the-year during the fall migration past Baffin Island in the eastern arctic by using size relative to that of a closely associated adult. Ljungblad (pers. comm.) has observed mother-calf pairs in Alaskan waters in autumn. Thus, it is clear that at least some calves remain in the company of their mother for the fall migration. There have been no reports of lone calves during spring or fall migration, but such animals would be difficult to detect. We know of no information concerning the age of weaning of bowhead calves, but some southern right whale calves remain with their mothers for one year and ultimately separate from their mothers after returning to the wintering area (Taber and Thomas 1982).

In order to compare the quantitative data on surfacing, respiration and dives that we have gathered for summering bowheads with similar data for migrating bowheads, we must use caution. Different investigators have gathered their information and defined their variables in somewhat different ways, because of differences in vantage point and in surfacing behavior of the whales. The comparisons that seemed valid are presented here.

In comparison with our results, Koski and Davis (1980) found longer blow intervals for Eastern Arctic bowheads migrating along the coast of Baffin Island in the autumn of 1979 (our data for non-calves 1980-1982: 13.5 $\pm$ s.d. 8.46 s, n = 2822; Koski and Davis: 16.1 $\pm$ s.d. 8.29 s, n = 399; t = 5.76, $p<0.001$).

The overall mean number of blows per surfacing that we recorded for non-calves in the eastern Beaufort Sea from 1980 through 1982 was 4.9 $\pm$ s.d. 3.61 (n = 322), less than the values reported for bowheads on their spring migration off Alaska by Carroll and Smithhisler (1980; mean = 6.5 $\pm$ s.d. 2.84 blows per surfacing, n = 41; t = 2.73, $p<0.01$) and by Rugh and Cubbage (1980; a mean of approximately 6.4 blows per surfacing). The overall mean length of surfacing that we observed in non-calves during 1980-82 was 1.3 $\pm$ s.d. 0.96 min (n = 368). This was slightly shorter than the approximate mean of 1.52 min that we derived from data collected by Carroll and Smithhisler (1980) from bowheads during spring migration. Our value was between the means reported for bowheads during fall migration in the eastern arctic by Davis and Koski (1980; mean = 1.2 min, n = 16) and Koski and Davis (1980; mean 1.7 $\pm$ s.d. 1.01 min, n = 93; in comparison with our data, t = 3.55, df = 459, $p<0.001$).

The length of dive that we observed in undisturbed non-calf bowheads during summer varied more from year to year than did the previous variables and had an overall mean from 1980-82 of 6.3 $\pm$ s.d. 7.65 min (n = 156, range = 0.03 to 31.0 min). Braham et al. (1979) reported that dives of whales migrating past Cape Lisburne, Alaska, in spring ranged from 1.7 to 28 min, but those authors did not give a mean. Carroll and Smithhisler (1980) found long dives, 15.6 $\pm$ s.d. 5.0 min (n = 63), during spring migration; and Koski and Davis (1980) found somewhat shorter dives of 8.65 $\pm$ 2.73 min (n = 88) duration during autumn migration in the eastern arctic. Both of these mean dive times for migrating bowheads exceed our overall 1980-82 mean for summering whales. However, our results from the summer of 1982 (12.08 $\pm$ 9.15 min, n = 51) are more similar to previous observations during migration.

Bowhead whales on their summering grounds, including the eastern part of the Alaskan Beaufort Sea up to mid September, appear to have the same basic repertoire of behaviors as do migrating bowheads. However, summering vs. migrating bowheads differ in the relative amounts of time spent in different activities--feeding, socializing, breaching and other aerial behavior, and travelling. At least some of the differences appear to occur as a continuum between seasons rather than an abrupt change. Travelling is the predominant activity during spring and fall migrations, while feeding is the predominant activity during summer. The average length of stay in any one area is therefore longer in summer, but considerable travelling occurs in summer and some feeding occurs during at least the fall migration. While quantitative comparisons of surfacing, respiration, dive and acoustic characteristics are not always possible and need to be treated with caution, there appear to be some significant differences between the seasons.

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Appendix. Summary statistics for the principal surfacing, respiration and dive variables in presumably undisturbed bowheads, 1980 through 1982.

		Blow interval (s)			Number of blows per surfacing			Surface time per 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	1980	12.9	8.61	915	4.8	2.91	70	1.25	0.723	94	2.25	3.549	25
	1981	13.0	8.08	1113	4.2	2.91	194	1.06	0.764	204	3.80	4.986	80
	1980-81	12.9	8.32	2028	4.3	2.91	264	1.12	0.756	298	3.43	4.715	105
	1980-82	13.5	8.46	2822	4.9	3.61	322	1.30	0.960	368	6.26	7.648	156
	1982	14.9	8.66	794	7.4	5.11	58	2.05	1.320	70	12.08	9.153	51
Calves (surfacings with nursing excluded)	1980	15.1	10.30	30	3.3	2.06	4	0.71	0.472	5	1.80	1.958	3
	1981	11.6	7.65	34	0.8	1.47	11	0.70	0.569	16	1.02	1.503	6
	1980-81	13.2	9.10	64	1.5	1.92	15	0.70	0.536	21	1.28	1.588	9
	1980-82	16.5	13.98	164	2.9	2.57	34	1.18	1.188	42	5.51	5.563	38
	1982	18.6	16.05	100	4.0	2.49	19	1.66	1.459	21	6.82	5.715	29
Adults with calf	1980	14.1	6.65	49	3.2	3.13	6	0.91	0.683	9	0.96	1.692	5
	1981	15.1	5.30	91	3.9	2.98	11	1.38	1.065	13	9.99	7.707	10
	1980-81	14.7	5.80	140	3.6	2.96	17	1.19	0.939	22	6.98	7.643	15
	1980-82	16.9	8.27	317	5.1	4.22	37	1.76	1.417	45	7.96	6.590	37
	1982	18.6	9.46	177	6.4	4.77	20	2.30	1.593	23	8.62	5.862	22
All others (non-calves without calf)	1980	12.8	8.71	866	4.9	2.87	64	1.29	0.722	85	2.57	3.842	20
	1981	12.8	8.26	1022	4.2	2.91	183	1.04	0.738	191	2.92	3.791	70
	1980-81	12.8	8.47	1888	4.4	2.91	247	1.12	0.741	276	2.84	3.784	90
	1980-82	13.0	8.39	2505	4.9	3.53	285	1.24	0.862	323	5.73	7.900	119
	1982	13.8	8.11	617	8.0	5.25	38	1.93	1.164	47	14.70	10.361	29

Continued...

Appendix. Continued.

		Blow interval (s)			Number of blows per surfacing			Surface time per surfacing (min)			Length of dive (min)		
		mean	s.d.	n	mean	s.d.	n	mean	s.d.	n	mean	s.d.	n
Socializing whales*	1980	13.3	8.25	168	6.0	2.45	5	1.50	0.467	14	0.25	0.186	3
	1981	14.2	11.40	265	3.8	2.36	51	1.09	0.839	53	2.95	3.181	25
	1980-81	13.9	10.30	433	4.0	2.43	56	1.18	0.791	67	2.66	3.117	28
	1980-82	13.9	9.99	507	4.0	2.43	60	1.19	0.787	72	2.59	3.085	29
	1982	14.2	8.01	74	3.8	2.75	4	1.34	0.796	5	0.58	-	1
Non-socializing whales*	1980	12.8	8.69	747	4.7	2.94	65	1.21	0.753	80	2.52	3.707	22
	1981	12.6	6.68	848	4.3	3.07	143	1.05	0.739	151	4.19	5.603	55
	1980-81	12.7	7.69	1595	4.4	3.03	208	1.11	0.746	231	3.71	5.165	77
	1980-82	13.4	8.09	2315	5.1	3.80	262	1.33	0.997	296	7.10	8.126	127
	1982	14.9	8.73	720	7.7	5.15	54	2.10	1.341	65	12.31	9.096	50
Skim-feeding whales*	1980	13.7	11.36	30	-	-	0	-	-	0	-	-	0
	1981	16.4	12.90	48	2.8	2.05	13	0.67	0.702	12	3.34	4.258	9
	1980-81	15.4	12.33	78	2.8	2.05	13	0.67	0.702	12	3.34	4.258	9
Water-column feeding whales*	1980	11.8	5.45	105	7.7	2.14	7	1.57	0.574	12	-	-	0
	1981	12.3	4.32	68	6.1	2.28	10	1.59	0.763	12	10.31	6.800	2
	1980-81	12.0	5.03	173	6.8	2.31	17	1.58	0.660	24	10.31	6.800	2
Non-feeding whales*	1980	12.8	8.34	747	4.6	2.87	56	1.24	0.745	74	2.33	3.602	24
	1981	12.5	6.49	935	4.1	2.95	160	1.00	0.716	169	3.63	5.008	65
	1980-81	12.6	7.37	1682	4.2	2.93	216	1.07	0.732	243	3.28	4.687	89

Continued...

Appendix. Concluded.

			Blow interval (s)			Number of blows per surfacing			Surface time per surfacing (min)			Length of dive (min)		
			mean	s.d.	n	mean	s.d.	n	mean	s.d.	n	mean	s.d.	n
Depth (m)	16-50*	1980	12.3	7.23	89	5.9	2.97	40	1.37	0.578	60	4.28	4.567	11
		1981	13.2	9.48	649	3.9	2.58	132	1.01	0.731	138	4.05	5.224	58
		1980-81	12.7	8.36	1399	4.3	2.80	172	1.12	0.707	198	4.09	5.094	69
		1980-82	12.7	8.30	1420	4.4	2.80	175	1.12	0.704	201	4.41	5.381	71
		1982	12.0	2.56	21	6.3	2.31	3	1.46	0.384	3	15.52	2.923	2
	51-100*	1980	–	–	0	–	–	0	–	–	0	–	–	0
		1981	13.4	5.34	126	4.9	3.26	18	1.20	0.809	18	6.57	4.232	8
		1980-81	13.4	5.34	126	4.9	3.26	18	1.20	0.809	18	6.57	4.232	8
		1980-82	13.9	5.67	140	4.4	3.28	21	1.07	0.821	21	4.87	4.585	11
		1982	18.1	6.97	14	1.3	0.58	3	0.26	0.207	3	0.33	0.073	3
	101-250*	1980	–	–	0	–	–	0	–	–	0	–	–	0
		1981	13.3	6.74	74	4.5	2.66	11	1.14	0.537	11	0.50	0.349	3
		1980-81	13.3	6.74	74	4.5	2.66	11	1.14	0.537	11	0.50	0.349	3
		1980-82	13.7	6.68	428	6.7	4.60	36	1.77	0.959	43	11.92	8.949	20
		1982	13.7	6.67	354	7.7	4.95	25	1.98	0.982	32	13.94	8.143	17
	>250*	1980	–	–	0	–	–	0	–	–	0	–	–	0
		1981	11.5	4.95	19	–	–	0	–	–	0	–	–	0
		1980-81	11.5	4.95	19	–	–	0	–	–	0	–	–	0
		1980-82	15.7	10.04	424	8.0	5.42	27	2.34	1.572	32	11.96	9.679	29
		1982	15.9	10.18	405	8.0	5.42	27	2.34	1.572	32	11.96	9.679	29

* Calves excluded.

DISTURBANCE RESPONSES OF BOWHEADS, 1982*

By

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ABSTRACT

Studies of the behavioral responses of bowhead whales to activities associated with offshore oil and gas exploration and development were conducted in the eastern (Canadian) Beaufort Sea during August 1982. This work was a continuation of similar studies conducted in late summer during 1980 and 1981. The overall objective in 1980-82 was to assess the short-term behavioral reactions of bowheads to noise and other stimuli associated with specific types of offshore exploratory activities now occurring in the Alaskan Beaufort Sea or likely to occur there soon. These include boat and aircraft traffic, seismic exploration, dredging and drilling.

In 1982, we emphasized studies of reactions to aircraft, seismic exploration and drilling, but collected some additional data concerning reactions to boats. This report presents the 1982 data and some previously unreported 1980-81 results in detail. It also re-examines some of the previously reported 1980-81 results for comparison and pooling with the 1982 data.

Methods in 1982 were very similar to those in 1980-81. The 1982 work was carried out in the Canadian Beaufort Sea throughout August. Both experimental and observational methods were used. During experiments, we tried to observe whales before, during and (when practical) after simulated industrial activity. In 1982, we conducted one boat disturbance experiment, two aircraft disturbance experiments, and three drilling noise playback experiments. Besides these experiments, we also observed whales in the presence and absence of aircraft, seismic exploration and drillships, and compared their behavior in these situations. Again in 1982, most observations were from a Britten-Norman Islander aircraft circling over the whales at an altitude of 457 m (1500 ft), which is high enough to avoid any major aircraft disturbance. Underwater sounds from whales and industrial sources were recorded via sonobuoys dropped from the aircraft and via hydrophones deployed from a boat. This boat was also used to conduct the playback and boat disturbance experiments.

The one **boat disturbance** experiment in 1982 was conducted in the presence of seismic noise with received level 132 dB//1 μPa. This trial replicated a 1981 experiment with the same 13-m boat in the presence of stronger seismic noise (about 150 dB). In both cases, the whales began to swim rapidly away as the boat closed to within 2-3 km. Thus, bowheads react strongly to an approaching boat even when they have already been exposed to intense sounds from seismic exploration before the boat approaches.

Reactions to an Islander **aircraft** were evaluated based on all data collected from 1980-82. New information from 1982 included (1) two experiments in which we circled above whales at 457 m (1500 ft) and then descended to 305 m (1000 ft), (2) a comparison of behavior observed from the aircraft and from a quiet, drifting boat, and (3) subjective interpretation of apparent reactions of whales to the observation aircraft on other occasions.

Based on results from 1980-82, we conclude that bowheads often dove precipitously in response to the Islander aircraft when it first approached at 305 m above sea level (a.s.l.), and occasionally did so when we approached at 457 m. In each of the four altitude experiments to date (two in 1982, two in 1981), mean interval between blows decreased when the aircraft descended from 610 m a.s.l. to 457 or 305 m, or from 457 m to 305 m. This tendency was not evident in the pooled data exclusive of the experiments or in small samples of data collected in the presence and absence of the aircraft. The discrepancy may reflect the greater sensitivity of the four controlled tests on particular bowheads. Excluding data from those experiments, mean lengths of time at the surface per surfacing were slightly reduced when the aircraft circled at 457-518 m relative to those when it circled at 610 m, but there was no clear evidence of effects on respiration or dive characteristics. In general, reactions to a circling aircraft were conspicuous if it was at 305 m, occasional but not major at 457 m, and undetectable at 610 m.

We observed bowhead behavior in the presence of noise from full-scale **seismic exploration** on four days in 1982 and four days in 1980-81. There was no clear evidence that these whales were attempting to move away from the seismic ships. Bowheads usually continued to produce their normal types of calls in the presence of seismic sounds.

Detailed comparisons of surfacing and respiration behavior of bowheads in the presence and absence of seismic noise have provided inconsistent results. In some but not all incidents, there have been indications that the usual cycles of surfacing, respiration and diving were modified by the seismic activity. This was so on three occasions in August 1982 when bowheads were seen 40-73 km from a vessel firing airguns. The apparent effects were detectable only by a detailed quantitative analysis of the data, and were not conspicuous to experienced observers watching the animals. On other occasions, including two incidents when a seismic ship was firing sleeve exploders 13 and 6-8 km from whales, no similar effects on behavior were detected even by detailed numerical analysis.

Differences in seismic sound levels near the whales do not explain the apparent inconsistency in the results. Peak levels of seismic sounds near the whales on the three occasions in 1982 when effects appeared to be present were 107-133 dB//1 μPa, or some 15-40 dB above the ambient levels prevailing at those times in the 10-500 Hz band. Levels near the seemingly undisturbed whales 6-13 km from a seismic ship were higher, about 141-150 dB.

During two controlled experiments with one 40 in^3 airgun fired 5 and 3 km from bowheads in 1981, we found slight indications of altered surfacing, respiration and diving cycles. The trends were consistent with those seen 40-73 km from full-scale seismic operations with airgun arrays. Also, during one of these experiments, the whales stopped calling.

We suspect that the apparent inconsistencies in the results concerning surfacing, respiration, diving and calling are a result of two main factors: (1) actual differences in the responses of the whales to seismic noise on different occasions, including possible habituation to ongoing seismic, and (2) difficulties in detecting subtle behavioral effects in the presence of great variability in natural behavior. However, the results show quite clearly and consistently that summering bowheads normally do not swim away from seismic vessels operating 6 km or more away. The importance of the subtler behavioral reactions that sometimes seem to occur is not known. Distributional evidence indicates that bowheads continue to use summering areas where seismic exploration has been in progress each summer for many years.

Drilling from artificial islands has not been in progress during our field seasons. However, we did see bowheads as close as 10-12 km from an operating drillship in 1982, and as close as 4 km in 1981. Industry personnel reported closer sightings. The strongest tonal sound from the drillship at 4 km range was about 111 dB//1 μPa at 278 Hz. There was no consistent indication of unusual behavior among whales observed within 20 km of drillships.

On two occasions in 1982, we completed controlled experiments in which we broadcast drilling noise into the water near whales whose behavior was observed both before and during the playback period. Calling rate apparently decreased during playbacks. There was some indication that the whales increased their rate of dispersal away from the site of the underwater projector during the playback period. However, the sample size was small and the reactions were not as conspicuous as those to close approach by a boat.

INTRODUCTION

In recent years, much concern has been expressed about possible effects of offshore oil and gas exploration and development on bowhead whales. The Western Arctic stock of this species, which is officially considered to be endangered, moves through several existing or proposed oil lease areas during its annual cycle of travel. Possible impacts on bowheads are one of the main environmental concerns with respect to leases in the Alaskan Beaufort Sea, since the whales travel and feed rather close to shore during their westward migration through this area in September and October.

The concern about deleterious effects of offshore oil exploration on bowheads has centered around two main types of potential effects: (1) direct contamination by oil released via a blowout or spill, and (2) disturbance effects. This study concerns disturbance effects. These effects could, in theory, take several interrelated forms, including short-term behavioral reactions, masking of sounds, displacement from particular areas in the short and/or long term, physiological effects including stress, and effects on population parameters such as reproductive rate. Previous literature concerning disturbance effects on marine mammals has been reviewed by Geraci and St. Aubin (1980), Acoustical Society of America (1981), Fraker et al. (1982), Richardson and Greene (1983) and, in most detail, Richardson et al. (1983b).

In response to concerns about possible disturbance of bowhead whales by offshore oil and gas exploration and development, the U.S. Bureau of Land Management funded a study of the behavior and disturbance responses of bowheads in the Beaufort Sea. Results from the first two years, 1980 and 1981, are reported in Richardson (ed., 1982). The work was continued in 1982 under the auspices of the U.S. Minerals Management Service. The present volume contains the results from 1982, with considerable integration of all results from 1980 to date. The study as a whole has concentrated on

- behavior of bowheads in the absence of industrial activities (Würsig et al. 1982, 1983),

- short-term behavioral reactions to nearby industrial activities (Fraker et al. 1982; this report),
- characteristics of noise from these industrial activities (Greene 1982, 1983),
- distribution of summering bowheads in 1980-82 in relation to the area of offshore oil exploration in the eastern Beaufort Sea (Richardson et al. 1983a), and
- characteristics of bowhead feeding areas (Griffiths and Buchanan 1982).

The main types of industrial activities investigated in this study have been boat and aircraft traffic, seismic exploration, dredging and drilling. All of these activities are major components of offshore oil exploration on continental shelves. All are either already underway or anticipated as components of offshore exploration in the Alaskan Beaufort Sea. Limited information about reactions of bowheads to each of these activities was obtained in 1980-81.

Objectives in 1982

Minerals Management Service specified that the highest priorities for 1982 were experimental and observational studies of reactions of bowheads to aircraft traffic and to drilling noise. Studies of reactions to geophysical survey vessels ('seismic') and to construction activity (dredging) were secondary priorities, and studies of normal behavior were a third priority.

Approach in 1982

The study area and study period in 1982 were basically the same as in the previously reported 1980-81 work. The work was again done in the eastern (Canadian) part of the Beaufort Sea. Study conditions, e.g. day length, weather, ice conditions and accessibility of bowheads, are relatively favorable there. Also, the occurrence of extensive offshore oil exploration in the Canadian Beaufort Sea provides opportunities to observe the distribution and behavior of bowheads near a variety of full-scale industrial activities, including some that are not yet underway in the Alaskan Beaufort

Sea. The accompanying section by Richardson et al. (1983a) describes the exploratory activities now underway in the eastern Beaufort Sea.

The behavior of the whales in the Canadian Beaufort Sea in August is similar to that in the Alaskan Beaufort Sea during much of September--feeding, socializing and intermittent travelling (Würsig et al. 1982, 1983; cf. Ljungblad 1981, in prep.). Hence, we believe that results from this study will apply more or less directly to bowheads in the Alaskan Beaufort Sea before the onset of rapid westward travel in late September or October.

The approach in 1982 was also similar to that in 1980-81. We again used a combination of (1) controlled experiments simulating industrial activities, and (2) opportunistic observations of distribution and behavior near ongoing full-scale industrial operations. The controlled tests involved observations of the behavior of a particular whale or group of whales before, during and sometimes after exposure to simulated industrial activity. This approach provided a way to detect alterations of behavior attributable to industrial disturbance despite the presence of great natural variability in behavior. The opportunistic observations were more difficult to interpret because of the lack of control and simultaneous variations in many environmental variables. However, they provided evidence about the presence and behavior of whales near full-scale activities that we could not simulate adequately.

Noise is one attribute of offshore oil exploration and development that may have a deleterious effect on marine mammals (Richardson et al. 1983b). Some of our experimental approaches have involved testing the reactions of bowheads to noise in the absence of other types of stimuli (e.g. drilling noise playback experiments in 1982; firing an airgun to simulate a seismic ship at longer range in 1981). In almost all of our work relating to disturbance, we have used sonobuoys and hydrophones deployed near whales to record industrial and natural sounds in the water. Characteristics of these industrial sounds are described in companion reports by Greene (1982, 1983). His results have been used in this report during interpretation of the reactions (or lack or reactions) of bowheads to industrial activities.

GENERAL METHODS

As in 1980-81, most behavioral observations were made from a Britten-Norman Islander aircraft circling over the whales. Some observations were made from a 13-m diesel powered boat, the MV 'Sequel', which was also used to deploy hydrophones and playback equipment, and to perform a boat disturbance experiment. The same aircraft was used in 1980-82, and the same boat in 1981-82. Both were again based at Tuktoyaktuk, N.W.T.

Aerial Observation Procedures

The aircraft carried special equipment important for our work. It had radar with ground-mapping capability, which we used to measure distances to ships, islands, etc. It had long-range fuel tanks, inverters to provide AC power, and windows that opened for unobstructed photography from each right-side seat. Positions and flight tracks were recorded manually from an OnTrac VLF/Omega navigation system.

Flight routes were chosen to search within the general areas where we expected to find whales. During flights when no specific disturbance experiment was planned, the flight route normally was planned to pass near several sites of ongoing offshore industrial activities (e.g., drillships, artificial islands). If whales were found near these sites, we usually stopped searching for whales and circled to observe the behavior of those near the industrial activity. If no whales were found near any of the industrial sites, we searched for whales elsewhere, emphasizing areas to which the boat could be directed for later disturbance experiments.

When whales were found far from any industrial activities, we usually circled to observe their 'normal' behavior (Würsig et al. 1983). If aircraft endurance permitted, we tried to observe these whales first from an altitude of 457 m above sea level (1500 ft a.s.l.), and then we descended to 305 m (1000 ft) to test their reactions to the observation aircraft.

While searching for whales in 1982, we flew at 457 m a.s.l. when cloud cover was no lower than that. We sometimes searched for whales when clouds forced us to fly lower, but we normally did not attempt to circle and observe whale behavior under these conditions. Work in 1980-81 indicated that the whales could not be assumed to be 'presumably undisturbed' by the aircraft when we circled below 457 m (Fraker et al. 1982). We usually did not fly when wind speed exceeded 25 km/h. Whales are difficult to detect and to observe in more severe conditions.

When we circled whales to observe behavior, we maintained an altitude of 457 m (except during aircraft disturbance experiments). If sufficient whales were present to allow a choice, we selected one or more well marked individuals to observe. When this was possible, we could re-identify an individual from one surfacing to the next. Near the start of the observation period, we normally dropped one or more dye markers to identify the approximate location of the whale during dives. Dye markers consisted of fluoroscein in water within a small plastic bag that burst upon impact with the sea. Usually we also dropped an AN/SSQ-57A sonobuoy with the dye markers near the start of the observation session.

Information about distances to any nearby vessels, islands, or other industrial activities was recorded frequently throughout the observation session. Distances were measured with the aircraft's radar when the industrial site was within range. Otherwise, distances to known industrial activities were determined indirectly by using the aircraft's VLF navigation system to record the whale's location. The accuracy of the VLF system was checked during each flight by comparing the indicated and actual latitude and longitude coordinates of known sites.

The nature of the industrial activity, e.g. whether a nearby drillship was drilling during an observation session, was determined either by direct radio communication from the aircraft or subsequently from the records of the operator. Underwater sounds detected by the sonobuoys also provided important information about industrial activities, e.g. whether noise from a distant seismic ship was detectable at the whale's location.

Behavioral observation procedures while we circled are described in detail in Würsig et al. (1983). The aircraft crew consisted of the pilot and four biologists. Two biologists on the right side of the aircraft dictated observations into the intercom system, which was connected to tape recorders. Another observer on the right side operated a videotape recorder whenever the whale(s) under observation were at the surface. The fourth biologist, on the left side, operated the sonobuoy receiving system and watched for bowheads on the 'outside' of the observation circle. Table 1 in Würsig et al. (1983) is a list of the dates, times and locations where behavioral observations were obtained in 1982; it includes information about nearby industrial activities. Würsig et al. also list the behavioral variables recorded routinely during the observation sessions, and describe the procedures used for transcription, coding and analysis of the data.

The present report presents considerable reanalysis of relevant data collected in 1980 and 1981 by Fraker et al. (1982). Some values presented here differ slightly from those in Fraker et al. because we now (1) exclude data from calves in routine analyses, and (2) include dive and surface times whose lengths are imprecisely known as long as the error could not exceed 5%. Also, some corrections to the 1980-81 data files have been made based on further manual and computerized validation of those data.

Experiments in 1982

In addition to opportunistic observations in the presence and absence of industrial operations, three types of experiments were conducted in 1982: two aircraft disturbance experiments, one boat disturbance trial, and two drillship noise playback experiments (plus another incomplete playback experiment). In each case, the procedure was to observe the 'presumably undisturbed' behavior of one or more whales, and then to continue the observations as the source of potential disturbance was introduced. When possible, observations were to continue after the end of the period of potential disturbance. This procedure was the same as we employed in 1980-81 in boat, aircraft and airgun experiments (Fraker et al. 1982).

The strength of this procedure is that it allows each whale or group of whales to serve as its own 'control'. This minimizes the potential for confounding of the results by individual variation or extraneous factors such as location, water depth, food availability, etc.

Details of the procedures during each experiment are given in subsequent sections where the results are presented. The aircraft disturbance experiments could be done by the observation aircraft without additional logistic support; we simply observed the whales first from high altitude, and then descended to lower altitude. Boat disturbance experiments were not planned for 1982, but one was conducted when an opportunity arose. Procedures for both the aircraft and the boat disturbance experiments were similar to those that we employed for the same types of experiments in 1980-81 (Fraker et al. 1982).

The noise playback experiments required coordinated use of the observation aircraft and the MV 'Sequel', and were logistically more difficult than our other experiments in 1980-82. The boat crew had to approach within about 1 km of whales, turn off the motor, drift quietly until the aircraft crew had obtained an adequate sample of 'control' observations, and then broadcast drillship noise into the water. Observations during the first half hour after the boat's motor was turned off were not assumed to be 'presumably undisturbed'. Hence, it was necessary to obtain well over 1 h of observations after the boat began to drift before the playback began. Because of this, the endurance of the aircraft was a limiting factor; it was essential to position the boat near whales early during a flight in order to complete the experiment before the aircraft had to leave. Dispersal of the whales away from the boat during the pre-playback control period was an unavoidable problem.

A further and serious complication in 1982 was the occurrence of numerous bowhead calves in the only area where experiments were possible. Our permit under the U.S. Endangered Species Act and Marine Mammal Protection Act did not allow us to conduct experiments on calves. In both playback experiments that were completed, the playback period had to be delayed until calves moved away. Because of limited aircraft endurance, this prevented us from collecting a useful quantity of post-playback observations after either experiment. In a third playback experiment, a calf appeared during the playback period and the experiment was cancelled. In another instance, the boat was successfully positioned near whales but the playback was never begun because of calves in the area. Furthermore, the one boat disturbance experiment in 1982 was terminated prematurely when a mother and calf were found ahead of the vessel, apparently trying to 'outrun' it.

Recording and Analysis of Waterborne Sounds

The equipment and procedures used to record waterborne sounds are described in the 'Industrial Noise' section (Greene 1983). Two different systems were used--sonobuoys deployed and monitored from the aircraft, and a hydrophone deployed from the 'Sequel'. Analysis techniques applied to industrial noises and bowhead sounds are described in Greene (1983) and Würsig et al. (1983), respectively.

REACTIONS OF BOWHEADS TO BOATS

Boats are the most widespread source of potential noise disturbance to bowhead whales on their summering grounds in the eastern Beaufort Sea. Bowheads may also encounter boats during fall migration to the Bering Sea, but currently bowheads are rarely exposed to marine traffic on their wintering grounds or during spring migration. Boats are mobile, relatively numerous, and often quite noisy, thereby providing the potential for widespread or frequent ensonification of the water as well as for possible collisions with whales.

Previous work has shown that bowheads responded to boats in two main ways (Fraker et al. 1982). (1) Whales responded to nearby vessels by decreasing their mean time at the surface, number of blows per surfacing, and dive duration. Whales observed 3-4 km from an idling, stationary 16-m boat showed decreased mean surface times and mean number of blows per surfacing. (2) In addition, when boats closed to within 1-3 km, the whales swam rapidly from the vessels and scattered. Whales directly on a vessel's track initially tried to outdistance it, but typically turned off the track as the vessel came within a few hundred metres. On occasions when we could watch the whales after the vessel had passed, they ceased fleeing when the vessel was 1-5 km away. We found no evidence that whales vacated any general area in response to disturbance by a boat. However, their activities were temporarily disrupted and their spacings increased when they scattered in response to boats. The long-term effects of more frequent vessel disturbance cannot be determined from a short-term behavioral study of this type (see Richardson et al. 1983a).

Boat disturbance studies were not identified as a high priority in the 1982 phase of this study. However, one systematic boat disturbance experiment was conducted in 1982 using the MV 'Sequel', the same vessel that had been chartered for similar work in 1981 (Fraker et al. 1982). As was the case for one experiment in 1981, interpretation of the results of the 1982 experiment is complicated by the presence of seismic noise. In addition, opportunistic observations of whales were obtained from the 'Sequel' in 1982. Opportunities for detailed observations of whales in the presence of other vessels did not occur in 1982.

Methods

The 'Sequel', a former fishing boat, is powered by a single 115 hp diesel engine (GM 471) and has a cruising speed of 14 km/h. The crew consisted of the skipper, a behavioral observer, and an acoustician. Observations were conducted from the flying bridge.

When bowheads were encountered by the 'Sequel', the observer estimated boat-whale distances and whale orientations visually for each surfacing. It was generally not possible to follow specific whales through more than one surfacing because of difficulty in recognizing individuals after a dive. Whale orientations were recorded by relating them to the face of a clock, with 6 o'clock indicating a whale oriented directly toward the vessel, 12 o'clock indicating a whale oriented away, etc. (see Fraker et al. 1982, p. 165-166 for a more detailed description). For analysis, whales oriented from 10 through 2 o'clock were considered to be oriented 'away' from the boat, those oriented from 4 through 8 o'clock were facing 'toward' the boat, and those oriented at 9 or 3 o'clock were 'neutral'. 'Expected' values in statistical tests were weighted according to the proportion of a clock face represented in each category. Distance and orientation data were collected from 'Sequel' on 15, 16, 18 and 19 August 1982 northeast and east of Herschel Island, Yukon Territory (Y.T.), including observations during a boat disturbance experiment on 16 August (see below). These data were pooled with previously unreported data obtained by the same observer aboard 'Sequel' when she was off the Mackenzie Delta on 18, 19 and 25 August 1981. The pooled data were used for analysis of whale orientations relative to distance from the 'Sequel' under three conditions: (1) engine turned off within past 30 min, (2) engine off for over 30 min, and (3) vessel underway at various speeds.

On 16 August 1982, observers in the Islander aircraft directed the 'Sequel' toward a concentration of 6-11 whales near 69°44'N, 138°03'W, northeast of Herschel Island, where water depth is about 125-165 m. The aircraft crew observed bowheads from an altitude of 457 m a.s.l. during the five stages of the experiment summarized in Table 1. Whales were observed as the boat moved at slow speed (7.4 km/h) for 51 min, drifted quietly with engine off for 95 min, idled for 4 min, and moved at relatively high speed (13.0 km/h) for 44 min. Data on the principal surfacing, respiration, and dive characteristics, orientations, distance and bearing from 'Sequel', swimming speed, and general activity of whales within as much as 6 km of the boat were recorded by the aircraft crew for comparisons between the stages of the experiment. Whale sounds were recorded via a sonobuoy deployed near the initial position of the whales. For analyses of orientations, distances and bearings, individual whales were tallied only once during each stage of the experiment.

Seismic pulses from the 'GSI Mariner', operating 52-61 km to the north and northeast, were present throughout all stages of the experiment (see Seismic section, later). The 'GSI Mariner' was travelling eastward and firing its airgun array. The received levels of the seismic pulses were 127-132 dB//1 μPa; the ambient noise level between seismic pulses was 99-102 dB//1 μPa in the 10-500 Hz band (C.R. Greene, pers. comm.).

Table 1. Description of events in a boat disturbance experiment involving the boat 'Sequel' on 16 August 1982.

Time (MDT)	Event
14:04-14:55:11	'Slow Boat'--'Sequel' moves slowly (7.4 km/h at 1000 rpm) on a heading of 060°T toward 6 whales under observation by the Islander aircraft crew.
14:55:11-15:25	'Post Boat'--First half hour of drifting after 'Sequel' shut off engine.
15:25-16:30:24	'Quiet Boat'--'Sequel' drifting with engine off for more than 30 min.
16:30:24-16:34:25	'Idling Boat'--'Sequel' starts engine and idles at 1000 rpm.
16:34:25-17:18:35	'Fast Boat'--'Sequel' moves rapidly (13.0 km/h at 1500 rpm) on a heading of 330°T toward 8-11 whales under observation by the Islander aircraft crew.

Results

Boat-based Observations

Bowheads observed from the 'Sequel' appeared to orient randomly relative to the vessel, regardless of distance or whether it was stopped or underway (Table 2, Fig. 1). Analysis of pooled 1981-82 observations from 'Sequel' showed that orientations of whales within 900 m of 'Sequel' did not differ significantly from random during periods when the boat was underway, quiet for $\leq$30 min, or quiet for >30 min (chi-square = 2.16, 0.64 and 1.02, respectively, with df = 2 in each case). Similarly, orientations did not differ significantly from random for whales farther than 900 m from the boat during either 'engine off' condition; no data were available for the 'underway' condition. The length of time since the engine was shut off did not seem to affect the orientations of the whales at any distance. These data collected from the boat should be interpreted cautiously, as the sample sizes are small, the data were collected during seven days and in two years,

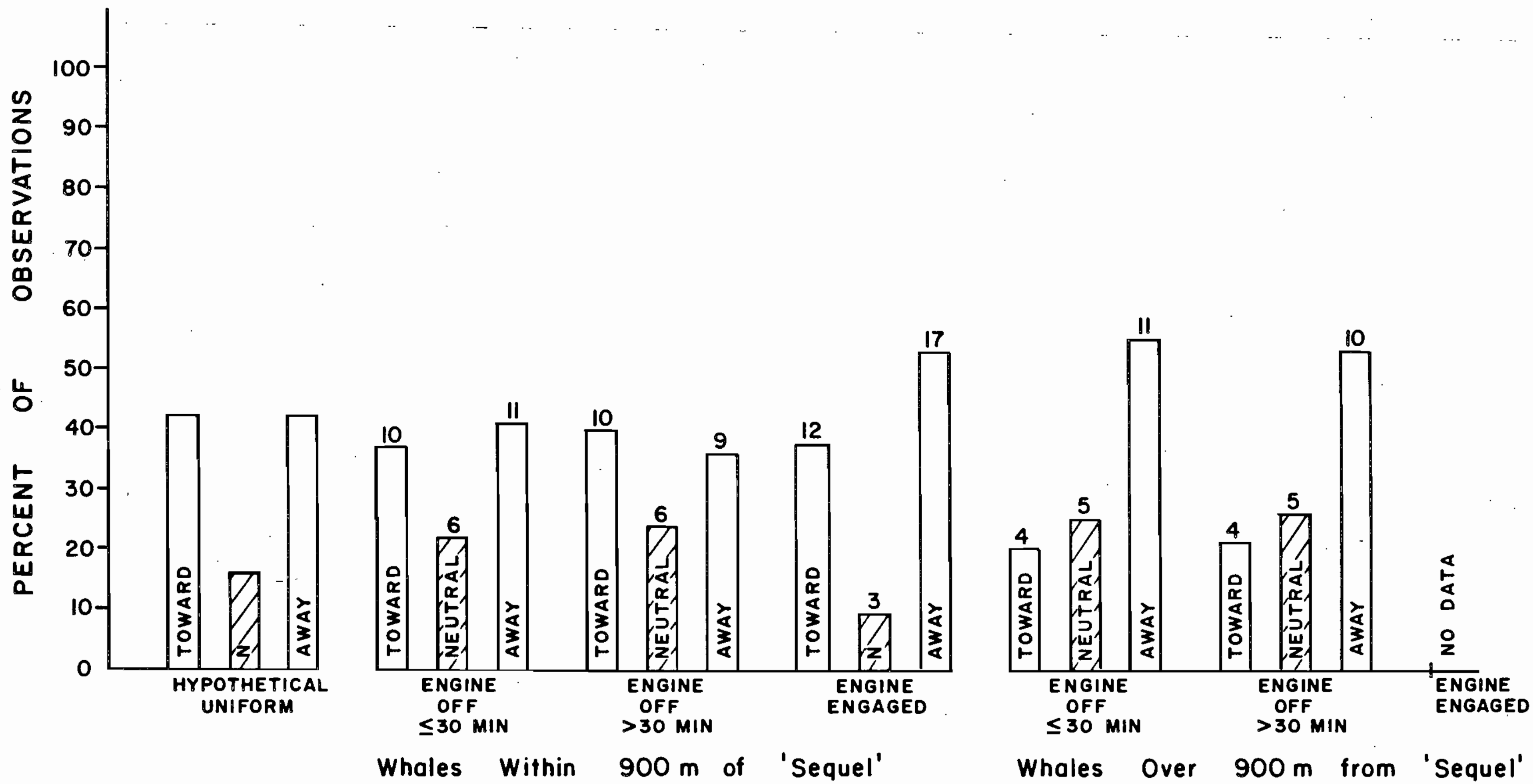


FIGURE 1. Orientations (with respect to boat) of bowhead whales observed from the boat 'Sequel' in 1981 and 1982. The hypothetical orientations are those expected if the whales were randomly oriented (see text). Numbers above bars are sample sizes.

Table 2. Orientations of whales observed from the 'Sequel' on 15, 16, 18, 19 August 1982 and 18, 19, 25 August 1981. The whales' orientations relative to the boat were recorded with respect to a clock face: 6:00 = toward the boat, 12:00 = away from the boat, etc. (see Fraker et al. 1982, for further details). Each individual was tallied only once for each surfacing.

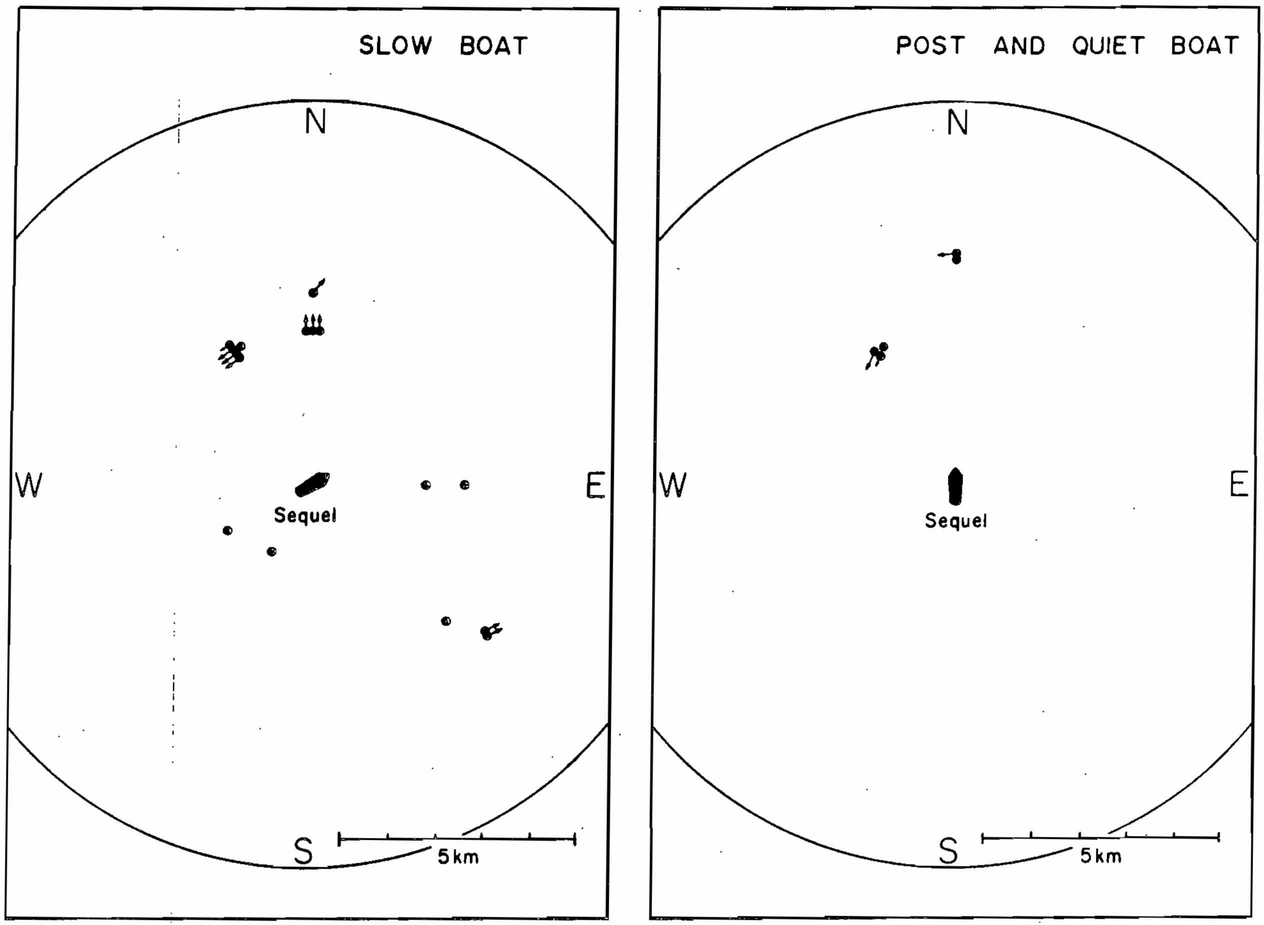
	Orientation							
	Away			Neutral	Toward			
Condition	12	11 + 1	10 + 2	9 + 3	8 + 4	7 + 5	6	Total
Engine off ≤30 min								
>900 m[a]	1	2	8	5	1	2	1	20
≤900 m	5	2	4	6	5	3	2	27
Engine off >30 min								
>900 m	0	2	8	5	1	2	1	19
≤900 m	4	2	3	6	5	3	2	25
Engine engaged								
>900 m	No Data							-
≤900 m	6	4	7	3	4	6	2	32

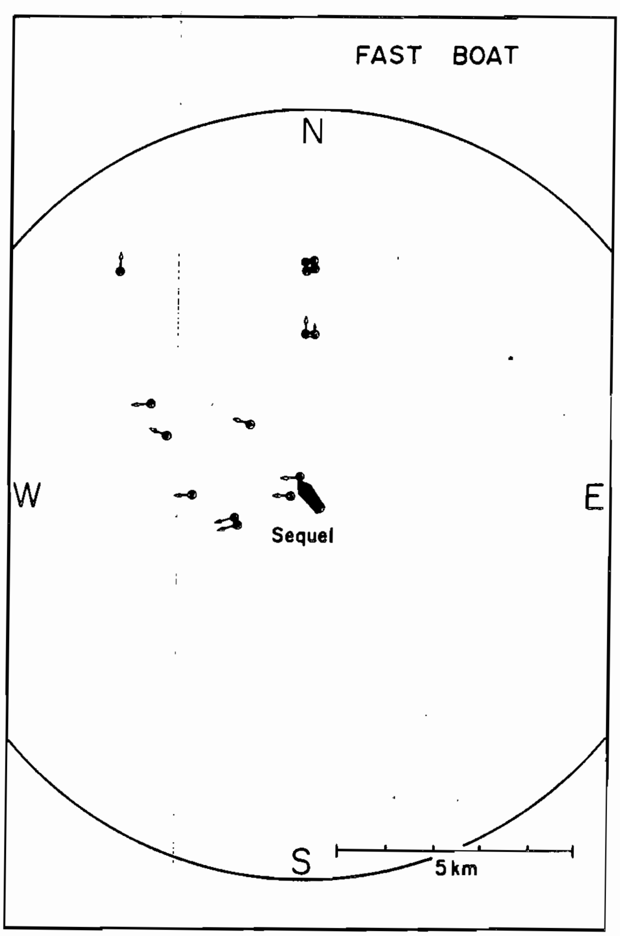
[a] Distance of whales from 'Sequel'.

and some data were collected in the presence of other types of possible disturbance aside from the boat itself.

Boat Disturbance Experiment

On 16 August 1982, bowheads responded strongly to 'Sequel's' approach by swimming rapidly away from the vessel. All observations described here were obtained from an aircraft circling 457 m a.s.l. overhead. When 'Sequel' moved rapidly (13.0 km/h), eleven whales for which orientation records were obtained by aerial observers oriented away from the boat. For ten of these whales, position relative to the boat was also estimated (Fig. 2). During the 'slow boat' (7.4 km/h) stage of the experiment, 7 of 11 whales observed by aerial observers oriented away; the other four whales were abeam of the vessel and oriented behind it. The three orientation records obtained while 'Sequel's' engine was off included whales oriented neutrally or toward the vessel. All seven records of medium or rapid swimming occurred while the boat was underway; all eight records of slow swimming or no forward movement occurred when 'Sequel' was drifting with its engine off. Sample sizes were





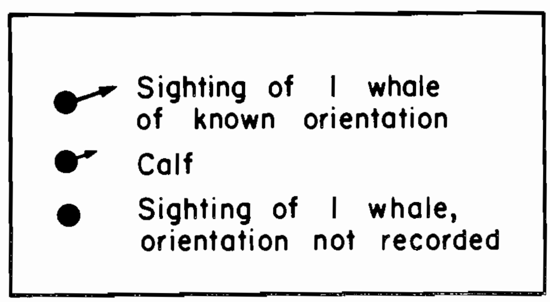


FIGURE 2. Positions and orientation of whales relative to 'Sequel' during the boat disturbance experiment on 16 August 1982. Each individual whale is tallied only once for each engine condition. All observations are from an aircraft circling overhead. Seismic noise was present throughout.

too small to define clearly the range of distances over which swimming speed and orientation were affected, but the whales apparently were reacting at distances at least as great as we have found in previous experiments. One whale 6 km from 'Sequel' oriented away from the vessel, and a mother-calf pair 3.4 km ahead of the boat swam rapidly away, within touching distance of each other, while the boat moved toward them at 13 km/h. The experiment was terminated when we noticed this mother-calf pair.

We did not detect any effects of engine condition or movement of 'Sequel' on surfacing, respiration, and dive characteristics of bowheads during the 16 August 1982 experiment. Analysis of variance for blow intervals found no significant difference between engine conditions (Table 3, Fig. 3). Comparison of mean blow intervals for the two extreme engine conditions, 'quiet boat' (engine off for >30 min) vs. 'fast boat', again found no significant difference. Sample sizes for other quantitative variables were too small for statistical comparisons; no consistent patterns relative to engine condition were found.

Loud calls by bowheads were heard much less often when the boat's engine was running (1 loud call in 47 min) than in the preceding period while the boat drifted quietly (22 loud calls in 65 min; data compiled by C.W. Clark). This may have reflected a reduction in calling rate in the presence of boat noise. However, increasing mean distance between the whales and the sonobuoy may also have been partly responsible.

Discussion

Fraker et al. (1982) described our previous results concerning reactions of bowheads to vessels, and Richardson et al. (1983b) reviewed the available literature about responses of marine mammals to vessels. Here we discuss, for the most part, only the new information from 1982.

The responses of whales to 'Sequel' as determined by boat-based observations were not nearly as marked as those to the 'Imperial Adgo' during 1980 (Fraker et al. 1982). Whales within 900 m of 'Adgo' oriented away from the vessel while its engines were idling or engaged. Differences between

Table 3. Surfacing, respiration, and dive characteristics of whales observed near the boat 'Sequel' on 16 August 1982. Seismic noise from the vessel 'GSI Mariner', 52-61 km away, was evident throughout the observations. Calves are excluded. All observations were by aircraft-based observers.

	Mean	s.d.	n
Blow Interval (s)			
Slow boat	14.69	6.053	35
Post-boat	17.64	9.805	22
Quiet boat	16.58	12.487	31
Idling boat	16.11	5.326	9
Fast boat	15.04	5.217	28
No. Blows/Surfacing			
Slow boat	9.00	5.196	3
Post-boat	8.00	-	1
Quiet boat	3.86	3.805	7
Idling boat	6.00	-	1
Fast boat	5.00	2.944	4
Duration of Surfacing (min)			
Slow boat	2.07	0.910	5
Post-boat	3.11	0.562	3
Quiet boat	1.45	0.924	8
Idling boat	1.78	0.094	2
Fast boat	1.38	0.758	3
Dive Duration (min)			
Slow boat	8.35	3.751	3
Post-boat	-	-	0
Quiet boat	5.94	7.994	8
Idling boat	1.42	-	1
Fast boat	11.48	12.457	2
Blow Rate (No. blows/min)			
Slow boat	0.89	0.740	2
Post-boat	-	-	0
Quiet boat	0.83	0.764	6
Idling boat	-	-	0
Fast boat	1.93	-	1

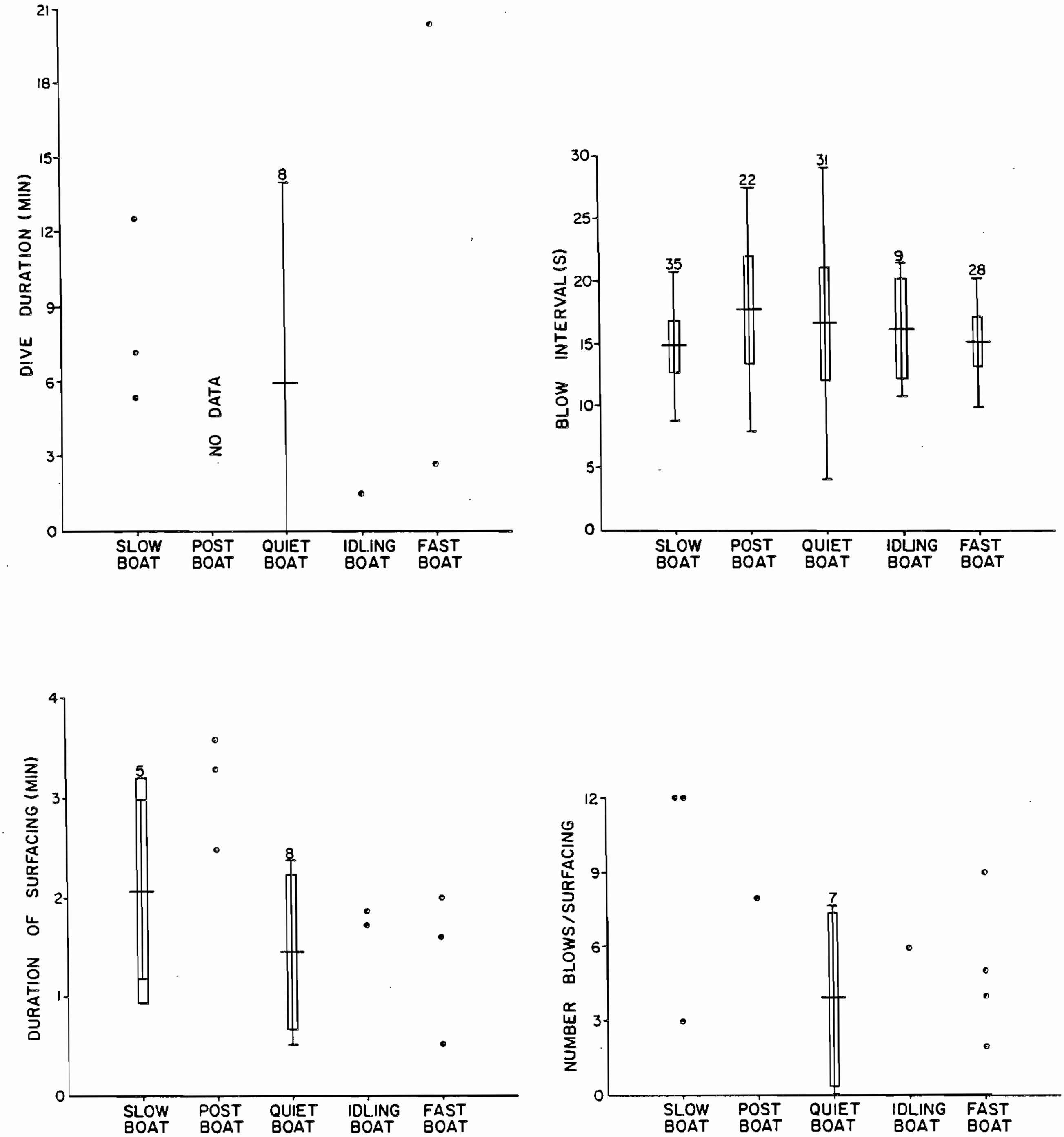


FIGURE 3. Surfacing, respiration and dive characteristics of bowheads observed near the boat 'Sequel' on 16 August 1982 in the presence of seismic noise. The mean, ± 1 s.d. (line), ± 95% confidence interval (rectangle), and sample size are shown. No 95% confidence interval is shown for dive durations, which were skewed. Individual points are plotted when the sample size is very small. Calves are excluded. All observations were by aircraft-based observers.

responses to the two vessels may be related to differences between vessels and to the manner in which the data were gathered. The 'Adgo', a 16-m twin-engine crew boat, is larger and faster (speed up to 41 km/h) than 'Sequel'. The responses to 'Adgo' were recorded within a 5-d period, whereas the data from 'Sequel' were obtained under a variety of conditions over seven days in two years. Such pooling may reduce the sensitivity of comparisons, since bowheads have many different behavior patterns and may react differently during different situations.

The pronounced flight response observed from the aircraft during the 1982 boat disturbance experiment was consistent with responses observed in a similar situation by Fraker et al. (1982). On 25 August 1981, 'Sequel' approached whales 8 km from an active seismic vessel. As the vessel approached to within 2.5 km, the whales ceased their play activity, next attempted to outdistance the vessel, and then turned to move at right angles to the boat's track. Rapid movement away from the vessel continued until the vessel, moving at full speed, was 5.6 km past the whales. The same types of responses were also observed during boat-whale interactions in the absence of seismic noise in 1980-81 (Fraker et al. 1982). However, during the two incidents studied in 1981, the responses occurred at greater distances from the vessels than during two incidents in 1980. Fraker et al. (1982) suggested that this seemingly greater sensitivity in 1981 may have been attributable to cumulative effects from multiple sources of potential disturbance. Responses observed during the 16 August 1982 experiment were evident at greater distances than during 1980, and also occurred in the presence of multiple potential disturbances (boat plus seismic noise). Thus, the 1982 experiment is consistent with the possibility that bowheads are more sensitive to boats when in the presence of multiple sources of potential disturbance.

Our results to date indicate that bowheads react strongly to close approach by a boat. The reaction is more conspicuous than to any of the other types of potential disturbance that we have studied. The fleeing response does not persist for long after the boat moves away, but increased inter-individual spacing sometimes continues longer (Fraker et al. 1982). This presumably causes some social disruption when the animals have been interacting before the boat arrives. The biological significance of this disruption is unknown. It is also unknown whether the disturbance effect might be more severe if the fleeing reaction were constrained by ice or shallow water, as might be the case if bowheads encountered vessels in leads.

REACTIONS OF BOWHEADS TO AIRCRAFT

The responses of bowheads to aircraft are of interest for several reasons:

1. Aircraft, particularly helicopters, are used extensively during offshore exploration for and production of oil and gas. Reactions of bowheads to aircraft could be one form of disturbance.

2. Most of our observations of bowhead behavior have been obtained from an aircraft circling overhead. It is important to confirm that the aircraft is not affecting the animals appreciably during these observations. For purposes of describing normal, undisturbed behavior of summering bowheads, whales observed from the aircraft while it circled at 457 m or more a.s.l. were considered to be 'presumably undisturbed' (Würsig et al. 1982, 1983). Observations from lower altitudes were considered to be 'potentially disturbed by aircraft' and were excluded from most of the analyses in Würsig et al. This criterion was based on analysis of behavior of whales observed while we circled above and below 457 m altitude during 1980-81 (Fraker et al. 1982).

3. Aircraft are often used to locate and census bowheads, and to estimate the size and age composition of the population (e.g., Ljungblad 1981; Cubbage and Rugh 1982; Davis et al. 1982). Knowledge of responses to an approaching or circling aircraft is important in assessing the reliability of this methodology. For example, differential responses of adults and calves to aircraft could bias aircraft-derived estimates of reproductive rate.

Observations during 1980 and 1981 suggested that our aircraft usually affected the whales' behavior when it circled whales at 305 m a.s.l. or below, but usually did not have a noticeable effect when it circled at 457 m. Typical reactions to the aircraft included some combination of reduced surface time, reduced blow intervals, and hasty initiation of a dive. No effects were detected when the aircraft circled at 610 m or above (Fraker et al. 1982). During 1982 we recorded additional cases of apparent disturbance owing to the presence of our aircraft, conducted two experiments comparing observations from 305 m and 457 m, and compared behavior during other periods when the aircraft circled at various altitudes. In addition, behavioral observations from a quiet boat were compared to those obtained from our aircraft under otherwise similar circumstances.

Methods

As in 1980-81, instances when observers in the aircraft believed that whales were being disturbed by the aircraft were recorded during periods of detailed behavioral observations and during searches for whales. The criteria used in assessing the occurrence of disturbance in these cases were somewhat subjective, but were based on considerable experience concerning the normal behavior of bowheads. Indications of disturbance included unusual changes in orientation, unusually rapid surfacings or dives, general movement out of the area under observation, and an abrupt initiation of tail slaps.

The opportunity to observe undisturbed whales in the absence of the aircraft occurred only once during each of 1982 and 1981. Though the samples were small, these observations provided a means for assessing the effects of a circling aircraft. On 15 August 1982, two adult whales were observed for 57 min (22:21-23:18 MDT) from the MV 'Sequel' as it drifted on a flat calm sea at 69°30'N, 138°13'W in water 128 m deep east of Herschel Island. The vessel had been drifting with engine off for 56 min prior to the initiation of observations. The whales were within 900 m of the vessel during observations. Surfacing and respiration characteristics of these two whales were compared to those of 'non-mother, non-calf' whales observed from the aircraft in the same area (and similar water depths) on 16 and 19 August 1982 under presumably undisturbed circumstances. The aircraft circled at 457 m a.s.l. altitude on both 16 and 19 August. Similarly, whales were observed from the Herschel Island shore station before the aircraft arrived on 3 September 1981. Because of variable ceiling conditions, the aircraft circled over whales at various altitudes from 152 m to 396 m over the next 57 min. As the whales under observation were 2.5-3.2 km from shore, only blow intervals could be recorded reliably from the shore station before and during the presence of the aircraft (Fraker et al. 1982). The results of this 1981 'shore vs. plane' experiment are included for comparison with the analogous 1982 results from 'quiet boat vs. plane'.

Two experiments were conducted in 1982 to examine the effects of aircraft altitude on the whales' behavior patterns. Using our Britten-Norman Islander observation aircraft, on 8 August 1982 we circled over and observed whales from 457 m for 89 min before descending to 305 m and observing whales in the same area for 68 min (Table 4). On 31 August 1982, a whale was circled at 457 m for 113 min before we descended and continued observations from 305 m for 99 min. Comparable experiments involving observations of whales from various altitudes were conducted on 6 and 8 September 1981 (Fraker et al. 1982). Observation altitude during 1981 ranged from 305 m to 610 m; details of these experiments are included for comparison with the 1982 study (Table 4).

Additional comparisons of the surfacing, respiration, and dive characteristics of bowheads observed from different altitudes were made using observations exclusive of those during the aircraft altitude experiments. Behavioral observations obtained when the aircraft was the only potential source of disturbance were categorized according to aircraft altitude: 427 m or less, 457-518 m, and 610 m a.s.l. and above. In 1982, all observations outside of the two altitude experiments occurred within the 457-518 m category.

Table 4. Summary of aircraft disturbance experiments during 1982 and 1981.

Date	Location	Time (MDT)	Aircraft Altitude (m a.s.l.)	Water Depth (m)	No. of Whales
8 Aug 1982	70°00'N	17:26-18:55	457	150-155	5
	138°00'W	18:57-20:05	305		
31 Aug 1982	70°30'N	10:15-12:08	457	550	1
	136°47'W	12:08-13:47	305		
6 Sep 1981	69°56'N*	17:53-19:18	610	53*	6-10?
	139°57'W	19:22-19:40	457		
		19:41-20:02	305		
8 Sep 1981	69°38'N*	21:12-22:00	610	26-30*	10-15?
	139°30'W	22:00-22:16	305		

* Locations and depths are approximate--aircraft VLF navigation system was

Results

Occasions with Apparent Reactions

Instances that were considered by observers aboard the aircraft in 1982 to be overt responses to the aircraft are presented in Table 5. This table includes six cases of notable variation from 'normal' patterns of movement and activity, as interpreted at the time of observation. Such interpretations were based on both instantaneous observations of changes in behavior, such as sudden and seemingly abnormal dives as the aircraft first approached, as well as changes that were apparent over longer periods of time. Observations during periods when other potential sources of disturbance were present (e.g., seismic noise, boat nearby) are not considered in Table 5.

Brief or rapid surfacings and dives, changes in orientation, and tail slaps were the most frequent apparent responses to our aircraft during 1982. Similarly, in 1980 and 1981 whales occasionally dove almost immediately in apparent response to the aircraft as it first approached at altitudes of 305

Table 5. Instances of apparent disturbance of bowheads by the Britten-Norman Islander aircraft during 1982. See text for discussion.

Obs. No.	Date	Aircraft Altitude (m a.s.l.)	Whale Activity	Apparent Reaction to Aircraft
1	4 Aug 1982	274	Rapidly travelling	Tail slaps
2	4 Aug 1982	274	Rapidly travelling	Changed orientation
3	4 Aug 1982	152	Unknown	Tail slaps
4	19 Aug 1982	457	Unknown	Gradual reduction in the number of whales within our circle of observation
5	24 Aug 1982	457	Adult-calf pair, travelling	Brief surfacings and dives
6	31 Aug 1982	457	Travelling	Turned on two occasions as aircraft approached

m or 457 m a.s.l. (Fraker et al. 1982, p. 189). In addition, whales sometimes moved gradually out of the area being circled, and we occasionally suspected that this was in response to the aircraft. On 19 August 1982 we circled an area that contained about 10 whales when we arrived. After we had circled for about 1.7 h, most of the whales had apparently left the area, possibly owing to the prolonged presence of the aircraft.

Our six observations of apparent disturbance in 1982 occurred when the aircraft was at various altitudes from 152 to 457 m a.s.l. Three of these observations were from 457 m, and three from lower altitudes. Except for the two experiments on 8 and 31 August, almost all of our detailed behavioral observations in 1982 were from 457 m. The three cases of apparent reactions to the aircraft when it was below 457 m were obtained when we flew below low clouds to search for whales. The relative frequency of conspicuous reactions to the aircraft at low altitudes was much higher than that when it flew higher, considering the small proportion of flying time spent at low altitudes.

During 1981, the four observations of apparent disturbance occurred when the aircraft was at an altitude of 457 m a.s.l. (3 cases) or 194 m (once). Again, we rarely circled at altitudes below 457 m in 1981. No overt responses were noticed when we were at altitudes above 457 m, although several flights involved observations from 610 m (Fraker et al. 1982). In 1980, observations were made from a wider variety of altitudes, including frequent observations from 305 m or less, as well as frequent observations from 610 m or more. All 17 instances of apparent disturbance in 1980 occurred when the aircraft was at 305 m or below.

These observations, although subjective, indicate that bowhead whales sometimes react immediately to an approaching Islander aircraft, generally by diving suddenly. Sudden dives are recognizable because the sequence of motions that normally occurs in the seconds before a dive is quicker or incomplete. This reaction is a short-term one and does not always occur when the aircraft approaches, even at altitudes less than 457 m. The observations provide some indication that prolonged circling may result in further changes in behavior, but this is less clearly evident than is the sudden dive that often occurs as an aircraft first approaches or first passes overhead. These observations also provide a strong indication that the degree of disturbance is related to the altitude of the aircraft; conspicuous reactions are rather frequent when the Islander aircraft approaches or circles at 305 m or less, infrequent when it is at 457 m, and not detected when it is at 610 m or more.

Behavior in the Presence and Absence of Aircraft

Behavior of two adult whales observed from the quietly drifting boat 'Sequel' on 15 August 1982 was compared to that of all 'non-mothers, non-calves' observed from the Britten-Norman Islander circling at 457 m a.s.l. in the same area on 16 and 19 August (Table 6). We excluded from these comparisons all observations obtained in the presence of other sources of potential disturbance, aside from the aircraft. For all variables considered, mean values derived from both observation platforms were within the usual ranges observed from the aircraft. However, the mean blow interval was significantly longer in the presence of the aircraft ($t = 2.58$, $df = 204$, $p<0.02$; Fig. 4). This result must be interpreted with considerable caution because the circumstances of the two sets of observations differed in several ways. Also, only two whales were observed in the absence of the aircraft, whereas observations from the aircraft involved many different whales.

Only one other opportunity to collect behavioral data in both the presence and absence of the aircraft has occurred. On 3 September 1981, whales were observed from the shore station on Herschel Island prior to the arrival of the Islander aircraft, and while the aircraft circled in the area at altitudes of 152-396 m (Fraker et al. 1982). Blow intervals observed from shore were quite similar ($p>0.6$) before and after the aircraft began circling (Fig. 4). However, this comparison is of questionable validity because the aircraft apparently was circling whales somewhat farther offshore than those being watched from shore. A more meaningful result is that blow intervals observed from the aircraft were also similar to those observed from shore ($p>0.5$; Fraker et al. 1982).

Table 6. Surfacing, respiration and dive characteristics of two bowheads observed from the boat 'Sequel' drifting quietly on 15 August 1982 in relation to those of 'presumably undisturbed'[a] 'non-mother, non-calf' whales observed from the Islander aircraft in the same general area on 16 and 19 August 1982.

Variable	Observation platform	Mean	s.d.	n	min	max
Blow Interval (s)	-'Sequel', 15 Aug	11.16	3.324	82	1	22
	-'Plane', 16 + 19	12.49	3.812	124	4	33
No. Blows/ Surfacing	-'Sequel', 15 Aug	14.50	3.391	6	8	17
	-'Plane', 16 + 19	12.22	2.682	9	7	16
Duration of Surfacing (min)	-'Sequel', 15 Aug	2.43	0.664	6	1.43	3.12
	-'Plane', 16 + 19	2.54	0.546	10	1.47	3.40
Duration of Dive (min)	-'Sequel', 15 Aug	16.77	6.220	5	9.57	25.03
	-'Plane', 16 + 19	17.88	1.638	2	16.72	19.03
Blow Rate (No. Blows/ min)	-'Sequel', 15 Aug	0.76	0.234	3	0.61	1.03
	-'Plane', 16 + 19	0.51	0.236	2	0.34	0.68

[a] All aircraft-based observations were collected while the Islander aircraft circled at an altitude of 1500 ft (457 m); occasions with seismic, boat and drilling noise are excluded.

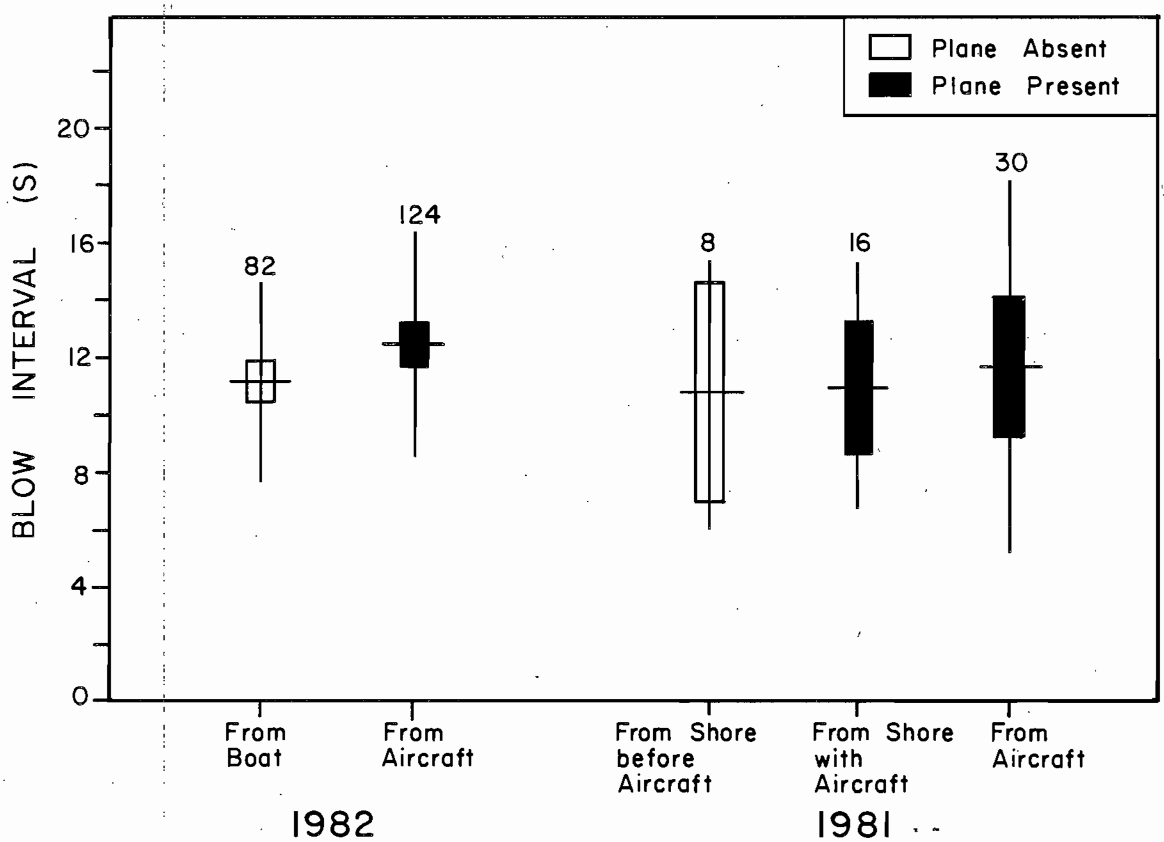


FIGURE 4. Blow intervals of bowheads observed in the presence and absence of the Britten-Norman Islander aircraft. The observation platforms are indicated along the bottom of the diagram. Calves are excluded. Presentation as in Figure 3.

While the 1982 observations suggest that there may be minor changes in the blow intervals of bowheads in the presence of an aircraft circling at 457 m a.s.l., the results are not conclusive.

Observations from Different Altitudes: Altitude Experiments

On four days in 1981 and 1982, we circled whales at high altitude and then descended to circle the same whales at lower altitude. This section compares the surfacing, respiration and dive characteristics of these whales as the aircraft circled overhead at various altitudes.

8 August 1982. -- Four non-calf whales and one calf were observed during an aircraft disturbance experiment on 8 August 1982. The aircraft circled first at 457 m a.s.l. and then at 305 m (Table 4). Blow intervals of non-calves were not statistically different while the aircraft was at 457 and 305 m, but tended to be shorter at the lower altitude (Table 7, Fig. 5). Significantly more blows per surfacing were observed when the aircraft was at 305 m altitude than when it was at 457 m ($t = 3.11$, $df = 10$, $p<0.02$). Dive durations were also significantly greater while the aircraft was at 305 m altitude (Mann-Whitney $U = 3$, $n = 4,7$, $p<0.05$).

Two individual whales, a calf and its presumed mother, were observed from both altitudes on 8 August 1982. The principal surfacing, respiration, and dive characteristics of these individuals are summarized in Table 7. As most of the observations during the experiment were of the mother, the similarities in the patterns for all non-calves and the mother are not surprising. As in the analysis of all 'non-calf' data, the number of blows per surfacing was significantly greater at the lower altitude ($t = 2.85$, $df = 7$, $p<0.05$). The mother tended to dive for longer periods when the aircraft circled at the lower altitude, but the difference was not statistically significant. Blow rates were significantly higher for the mother when the aircraft circled at 305 m a.s.l. ($t = 2.77$, $df = 5$, $p<0.05$). The mother's blow intervals tended to be shorter and time at the surface longer when the aircraft was at the lower altitude, but the differences were not significant. Sample sizes for the calf were very small, and we found no significant differences in any of the principal surfacing, respiration, and dive characteristics of the calf relative to aircraft altitude.

Table 7. Summary statistics for the principal surfacing, respiration, and dive characteristics of non-calf bowheads observed during aircraft disturbance experiments. Data for one calf seen on 8 August 1982 are included only in the two lines labelled "CALF".

Date	Altitude (m a.s.l.)	Blow Interval (s)			No. Blows per Surfacing			Duration of Surfacing (min)			Duration of Dive (min)			Blow Rate (No. blows/min)		
		Mean	s.d.	n	Mean	s.d.	n	Mean	s.d.	n	Mean	s.d.	n	Mean	s.d.	n
8 Aug 82*	457	14.96	6.905	23	3.44	2.297	9	1.15	0.595	10	6.57	4.216	7	0.52	0.526	6
	305	13.96	1.846	23	8.00	1.732	3	1.90	0.495	2	12.26	3.371	4	0.75	0.212	2
8 Aug 82	457	16.00	7.244	18	3.38	2.480	6	1.29	0.637	6	7.57	3.601	6	0.31	0.184	5
"MOTHER"	305	13.96	1.846	23	8.00	1.732	3	1.90	0.495	2	12.26	3.371	4	0.75	0.212	2
8 Aug 82	457	17.54	16.944	13	3.17	1.602	6	1.21	0.596	6	7.67	3.455	6	0.31	0.224	5
"CALF"	305	12.25	7.387	12	6.00	-	1	1.43	0.778	2	12.46	3.485	4	-	-	-
31 Aug 82	457	13.50	5.711	34	7.50	2.121	2	1.50	0.071	2	12.79	2.150	5	0.67	-	1
31 Aug 82	305	10.90	3.964	59	8.57	2.573	7	1.78	0.341	7	10.54	1.277	8	0.72	0.236	6
6 Sep 81	610	13.49	4.335	72	2.89	3.018	9	0.65	0.893	9	3.98	6.741	3	-	-	-
6 Sep 81	457	11.56	3.664	25	2.50	2.121	2	0.48	0.365	2	0.10	-	1	-	-	-
6 Sep 81	305	10.50	3.854	28	2.00	-	1	0.77	0.613	2	-	-	-	-	-	-
8 Sep 81	610	10.91	3.153	105	6.64	3.529	11	1.34	0.678	12	0.66	0.406	4	3.73	0.902	2
8 Sep 81	305	9.58	2.824	45	5.00	1.414	4	0.81	0.443	6	-	-	-	-	-	-

* These '8 Aug 82' lines include observations from 457 m of a mother and three other non-calves, and subsequent observations from 305 m of the mother only. The second pair of lines show the data for the mother alone.

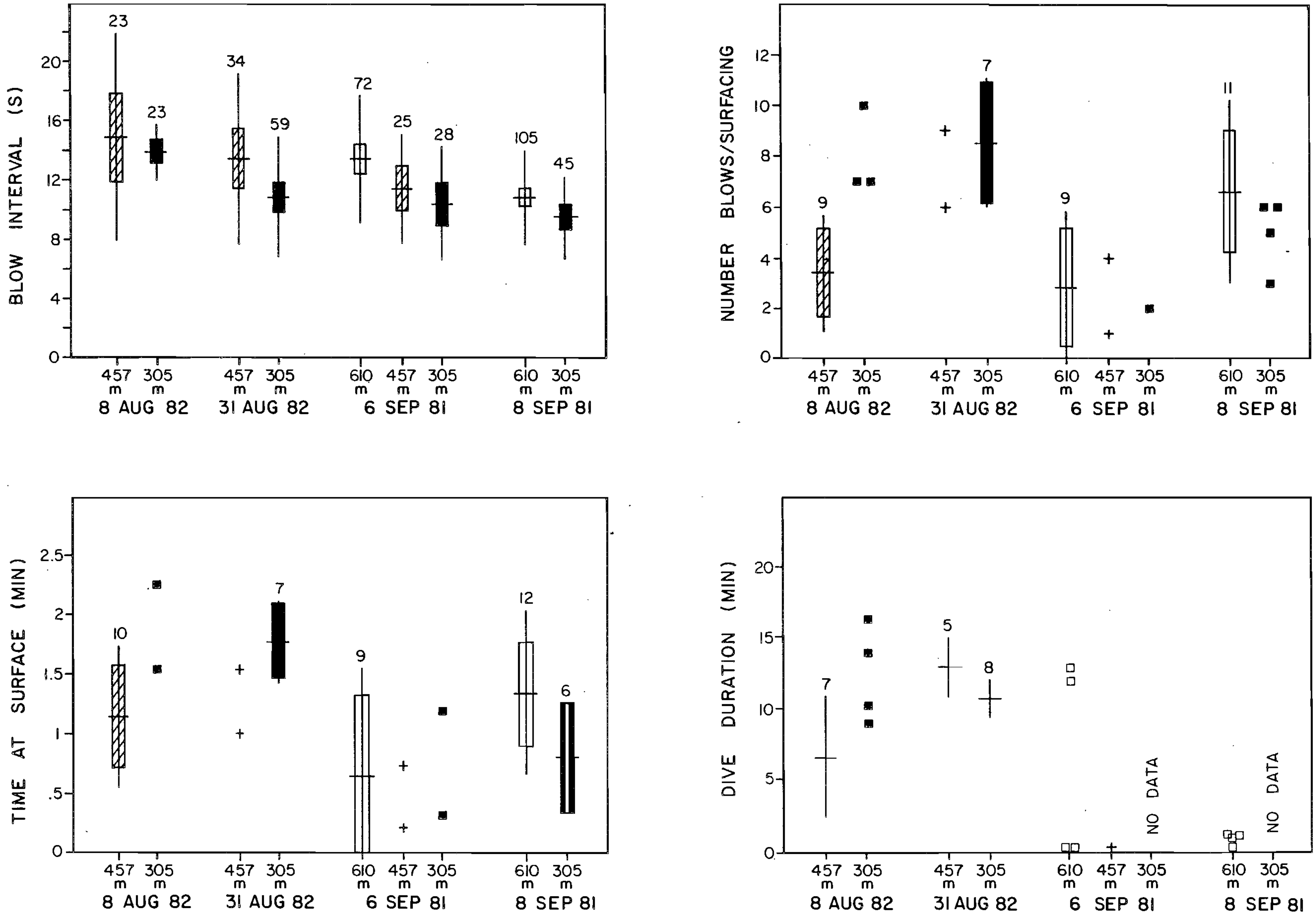


FIGURE 5. Surfacing, respiration and dive characteristics of bowheads observed from the Britten-Norman Islander aircraft at different altitudes on four dates. Calves are excluded. Presentation as in Figure 3.

31 August 1982. -- A single whale was observed during an experiment on 31 August 1982 (Table 4). As on 8 August, the whale was circled first at 457 m a.s.l. and then at 305 m. No other sources of potential disturbance were nearby, although a drillship and supply vessel were present about 18 km away. Blow intervals were significantly shorter when the aircraft was at the lower altitude (Table 7 and Fig. 5; t = 2.59, df = 91, p = 0.01). Sample sizes for other variables were small, and no other statistically significant differences were found. However, the number of blows per surfacing and duration of surfacing tended to be greater while the aircraft was at the lower altitude, as on 8 August 1982.

6 and 8 September 1981. -- Similar experiments were conducted on 6 and 8 September 1981 (Table 7, Fig. 5; Fraker et al. 1982). Some values presented here differ slightly from those in Fraker et al. because of new criteria for acceptance of data. In both experiments, blow intervals were significantly shorter when the aircraft was at the lower altitude(s). On 6 September the overall differences among the three altitudes were significant (ANOVA, F = 6.04, df = 2,122, p<0.01) and, in particular, blow intervals were shorter when the aircraft was at 457 m and 305 m than when it circled at 610 m (Student-Newman-Keuls multiple comparison). Similarly, on 8 September 1981 blow intervals were significantly shorter when the aircraft circled at 305 m than at 610 m (t = 2.45, df = 148, p<0.05). These results are consistent with those seen in the 1982 experiments. For other variables, no statistically significant differences were found during the 1981 experiments. However, the duration of surfacing and number of blows per surfacing tended to be less for whales circled at lower altitudes--contrary to the trends in 1982 (Fig. 5).

Turning. -- The incidence of turning was examined to test the assumption that changes in orientation are indications of disturbance by aircraft. Table 8 shows the number of surfacings during which turns did and did not occur while the aircraft circled at each altitude. In 1982, considering both experiments together, turns were slightly more frequent when the aircraft circled at 305 m a.s.l. than at 457 m, but the difference was not statistically significant (contingency chi^2 = 0.77, df = 1, p>0.3). When the aircraft was at 305 m, the percent of surfacings that contained turns (55%)

Table 8. Incidence of turning by non-calf bowheads observed during aircraft disturbance experiments in 1982 and 1981. The few socializing animals are excluded; turning frequency is higher for socializing bowheads (Würsig et al. 1983).

		Number of Surfacings				
		With Turns		Without Turns		Total No. of Surfacings
	Altitude (m a.s.l.)	Observed	Expected[a]	Observed	Expected	
8 Aug 1982	457	2	2.56	6	5.44	8
	305	0	0.96	3	2.04	3
31 Aug 1982	457	4	2.56	4	5.44	8
	305[b]	6	2.56	2	5.44	8
8 + 31 Aug 1982	457	6	5.12	10	10.88	16
	305	6	3.52	5	4.08	11
6 Sep 1981	610	5	4.32	13	13.68	18
	457	1	1.44	5	4.56	6
	305	3	1.68	4	5.32	7
8 Sep 1981	610	1	4.56	18	14.44	19
	305	1	2.40	9	7.60	10
6 + 8 Sep 1981	610	6	8.88	31	28.12	37
	457	1	1.44	5	4.56	6
	305	4	4.08	13	12.92	17

[a] Expected values from Würsig et al. (1982, 1983). In 1982, turns were observed in 32% of surfacings by undisturbed non-socializing whales. In 1981, the corresponding value was 24%.

[b] Chi-square = 6.80, df = 1, $p<0.01$

exceeded the 32% value for all 'presumably undisturbed' non-socializing whales in 1982 (Würsig et al. 1983). However, the difference was not significant (goodness of fit $chi^2 = 1.95$, df = 1, $p<0.3$). In 1981, similarly, there was no evidence that turns were more frequent when the aircraft circled at 305 m versus 610 m (contingency $chi^2 = 0.41$, df = 1, $p>0.5$). The sample sizes were too small for this analysis to be conclusive, but turning did not appear to be a consistent response to the aircraft.

Call Rates. -- A sonobuoy was deployed near the initial location of the whale(s) in each of the two 1982 experiments. Calling rates were lower when the aircraft was at 305 m a.s.l. than during the preceding period at 457 m. This may have been a real effect, but may also have been an artefact of the gradual increase in distance between whales and sonobuoy.

Summary. -- In each of the four experiments, blow intervals decreased when the aircraft descended. The overall trend was highly significant ($p<0.001$; Table 9). In contrast, a small set of observations in the presence and absence of the aircraft revealed longer blow intervals with the aircraft present (Fig. 4). We suspect that this latter trend is not attributable to aircraft disturbance, given the consistency of the decrease in blow intervals as the aircraft descended.

No consistent effects of aircraft altitude were evident from analysis of other variables. During one experiment, there was a significant increase in number of blows per surfacing when the aircraft descended, but this was not so in the other experiments and the overall trend was non-significant ($p>0.3$). Durations of surfacing did not differ significantly among aircraft altitudes in any experiment, and the pooled trend was non-significant ($p>0.6$). The sample size for duration of dives was always small, and trends differed among experiments (Fig. 5). There was no clear evidence that whales turned more frequently when the aircraft descended to lower altitudes.

Thus, a reduction in blow intervals as the aircraft descended was the only consistent effect attributable to the aircraft during the four experiments.

Table 9. Statistical comparisons of surfacing and respiration characteristics of bowheads during aircraft altitude experiments in 1982 and 1981. Dive duration is excluded because of low sample sizes (Fig. 5). Plus signs indicate that the mean value was greater when the aircraft was at low altitude; minus signs indicate that the mean was greater at high altitude.

	Experiments				
Parameter	8 Aug '82 457 vs. 305 m	31 Aug '82 457 vs. 305 m	6 Sep '81 610 m, 457 m 305 m	8 Sep '81 610 vs. 305 m	Pooled[a]
Blow Interval					
Type of Test	t	t	ANOVA	t	
Test Statistic	−0.67	−2.59	−6.04	−2.45	
df	44	91	2,122	148	
Probability	−0.51	−0.011	−0.003	−0.015	−,<0.001
z[a]	−0.66	−2.58	−2.97	−2.43	−4.32
No. Blows/Surfacing					
Type of Test	t	t	t (610 m vs. 457 m)	t	
Test Statistic	+3.11	+0.53	−0.17	−0.88	
df	10	7	9	13	
Probability	+0.011	+0.61	−0.87	−0.39	+0.31
z	+2.54	+0.51	−0.16	−0.86	1.02
Duration of Surfacing					
Type of test	t	t	ANOVA	t	
Test Statistic	+1.65	+1.09	± 0.063[b]	−1.74	
df	10	7	2,10	16	
Probability	+0.13	+0.31	0.95	−0.10	+, >0.6
z	+1.51	+1.02	(0.06)	−1.65	<0.47

[a] Pooled z and p values are based on the unweighted z method (Rosenthal 1978); z is the normal (0,1)

Observations from Different Altitudes: Overall Observations

Observations while the aircraft circled at different altitudes in situations exclusive of the altitude experiments provided additional data for assessment of possible aircraft disturbance. Only the results from 1980 and 1981 are useful for this analysis; in 1982 all behavioral observations (aside from those collected during altitude experiments) were collected while the plane was at or near 457 m a.s.l. (Table 10, Fig. 6). Analyses of variance for 1980 and 1981 revealed no significant differences among blow intervals when whales were observed from the three altitude ranges. Nevertheless, in 1980 the small sample of blow intervals observed when the aircraft was at or below 427 m a.s.l. (henceforth abbreviated ≤ 427 m) were long relative to those observed from both of the higher altitude ranges ($p<0.05$ in each case, t-tests). This result is inconsistent with results from all four aircraft altitude experiments, and may be an artefact of the small sample size for altitudes ≤ 427 m.

During 1981, mean duration of surfacing was significantly shorter when the aircraft circled at ≤ 518 m a.s.l. than when it circled at ≥ 610 m (ANOVA, $F = 4.68$, $df = 2{,}186$, $p<0.05$; Student-Newman-Keuls multiple comparison). However, in 1980 mean durations of surfacing were nearly equal for all altitudes.

No significant relationships of other variables to aircraft altitude were found. The number of blows per surfacing did not differ significantly among altitude categories, and trends were inconsistent from year to year. Durations of dives were not significantly related to aircraft altitude in either 1980 or 1981, but in both years there was a trend toward decreased dive time with decreased altitude. No significant or consistent patterns were found for blow rates relative to altitude.

Discussion

Evidence from observations during 1982 indicates that bowhead whales may alter certain of their behavior patterns in apparent response to the presence and altitude of aircraft. Real-time observations as well as statistical analyses of quantifiable behavioral characteristics reveal both overt and

Table 10. Summary statistics for the principal surfacing, respiration, and dive characteristics of non-calf bowheads observed while the aircraft was at various altitudes, exclusive of the four aircraft disturbance experiments.

Year	Altitude (m a.s.l.)	Blow Interval (s)			No. Blows per Surfacing			Duration of Surfacing (min)			Duration of Dive (min)			Blow Rate (No. blows/min)		
		Mean	s.d.	n	Mean	s.d.	n	Mean	s.d.	n	Mean	s.d.	n	Mean	s.d.	n
1980	610+	13.07	9.295	690	4.58	3.001	59	1.22	0.766	74	1.94	3.397	21	0.77	0.435	6
	457-518	12.29	6.152	200	5.50	2.619	8	1.29	0.652	12	0.18	0.189	2	-	-	-
	≤427	17.19	11.174	21	7.00	-	1	1.10	1.296	2	0.58	0.000	2	-	-	-
1981	610+	13.19	14.508	335	4.83	2.786	53	1.30	0.658	58	6.64	9.515	18	1.07	0.992	10
	457-518	13.18	16.548	576	3.81	2.763	119	0.96	0.781	123	3.15	5.213	54	1.27	1.096	26
	≤427	13.60	16.777	48	2.17	2.317	6	0.82	0.544	8	2.99	3.873	6	0.57	0.318	3
1980 + 1981	610+	13.11	8.361	1025	4.70	2.891	112	1.25	0.719	132	4.11	5.597	39	0.96	0.823	16
	457-518	12.95	9.160	776	3.91	2.775	127	0.99	0.774	135	3.04	4.096	56	1.27	1.096	26
	≤427	14.70	10.168	69	2.86	2.795	7	0.88	0.656	10	2.39	2.075	8	0.57	0.318	3
1982	610+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	457-518	14.91	8.817	738	8.19	5.257	47	2.22	1.368	58	12.97	10.023	39	0.76	0.464	18
	≤427	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

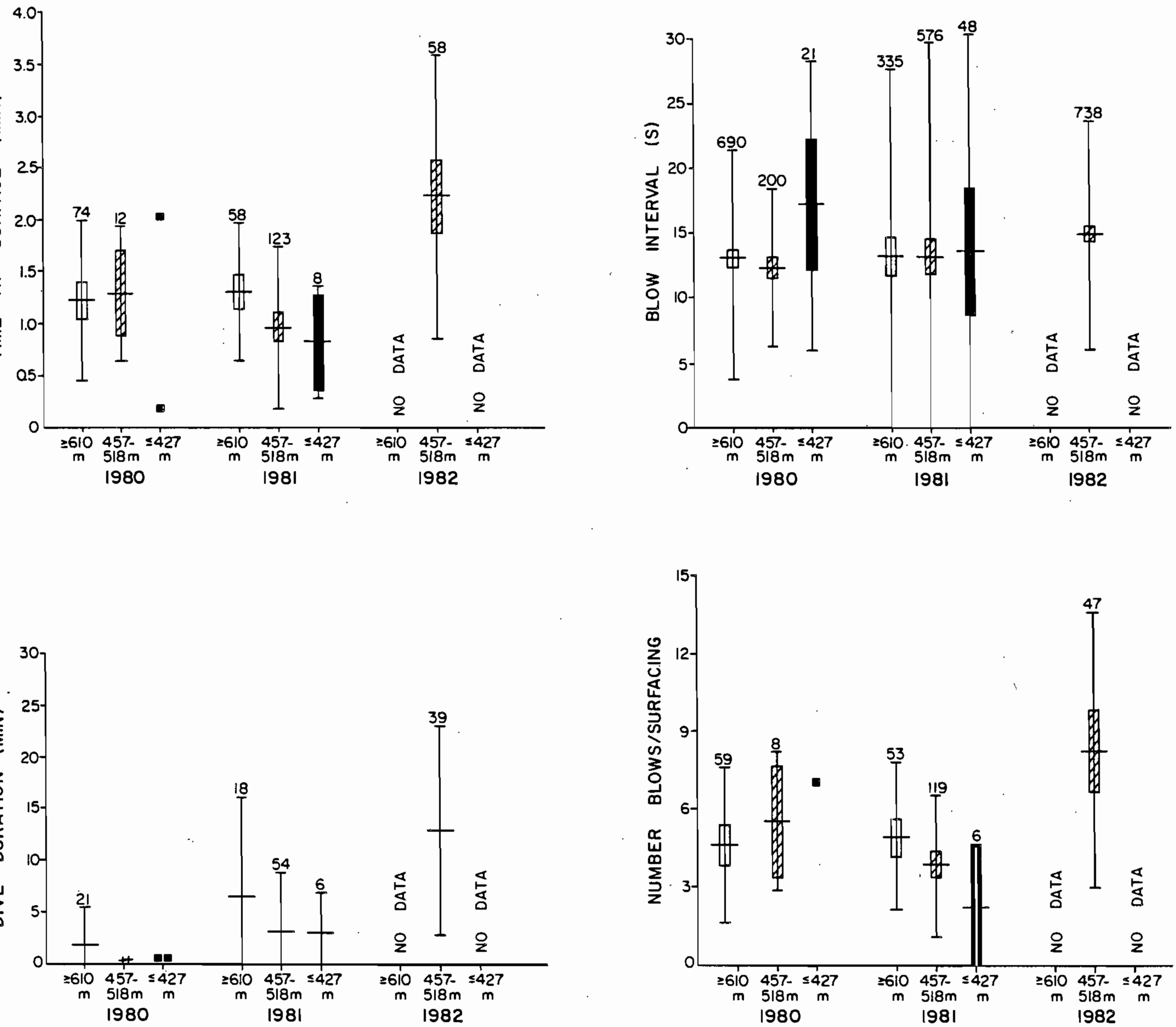


FIGURE 6. Surfacing, respiration and dive characteristics of bowheads observed from the Islander aircraft at three altitude ranges during 1980-82. Only observations under 'presumably undisturbed' conditions (except possibly by the aircraft) are considered. Calves are excluded. Presentation as in Figure 3.

subtle responses. Similar responses were evident from the 1980-81 data (Fraker et al. 1982).

Würsig et al. (1983) described typical behavior patterns for undisturbed whales. An undisturbed non-calf bowhead whale typically moves slowly ahead, turning during only 32% (in 1982) of non-socializing surfacings. On the average, surfacing sequences observed in 1982 lasted 2.05 $\pm$ 1.320 min and included 7.4 $\pm$ 5.11 blows, each separated from the next by 14.9 $\pm$ 8.66 s. The surfacing sequence is typically followed by a slow forward rolling movement that is followed 42% of the time (in 1982) by a slow lifting of the flukes from the water. Dives of 'non-calves' recorded in 1982 lasted 12.08 $\pm$ 9.153 min.

The most obvious apparent responses to aircraft include changes in surface and dive patterns, and in orientations. In previous years, apparent alterations to surface and dive patterns in response to the aircraft included nearly immediate dives upon our approach, with rolling and submergence occurring more rapidly than normal (Fraker et al. 1982). The immediate dives presumably resulted in shorter surfacings than usual. In 1982, we sometimes were able to remain with individuals for longer periods than in past years (up to 3.5 h), facilitating the collection of observations of more than just immediate apparent responses. On 24 August 1982, for example, a mother-calf pair was reported to be engaging in shorter than usual surfacings and dives, apparently as a result of the aircraft circling at 457 m a.s.l. In general, the degree of response appeared to be related to the altitude of the aircraft, with the most marked effects when the aircraft was below 427 m, occasional reactions at 457 m, and no detectable reactions at 610 m. Quantitative support for the impressions of reduced durations of surfacings in apparent response to aircraft is available from some of the experiments and other observations, primarily in 1981 (Figs. 5, 6). However, reduced durations of surfacings were not always evident when the aircraft circled at low altitudes. The quantitative data were virtually all obtained after the aircraft first approached the whales. In contrast, most cases in which the observers believed that the whales cut short a surfacing and dove precipitously occurred when the aircraft first approached the whales. These observations suggest that the effect of the aircraft on duration of surfacing is more pronounced when it first arrives than during subsequent surfacings.

Similarly, the observers have sometimes suspected that bowheads were turning in response to the initial approach of the aircraft, but analysis of limited data from the 1981 and 1982 aircraft altitude experiments found no consistent support for this impression. The quantitative analysis again is based mainly on observations after the aircraft had been overhead for some time.

Tail slapping bouts observed on two occasions during 1982 may have been in response to the aircraft. Aerial behaviors have not been reported as overt responses to the aircraft in previous years, and aerial behaviors occurred infrequently during all three years of observation (Würsig et al. 1982, 1983). Only seven other bouts of tail slapping, including two bouts by calves, were reported during 1982; three of these occurred during other forms of possible disturbance (seismic noise or drillship noise playbacks). Two bouts reported in apparent response to the aircraft occurred when the aircraft was at unusually low altitudes (152 m and 274 m). However, no aerial behaviors were observed during any phase of the aircraft altitude experiments, and data from other sources were too few to allow meaningful interpretation.

Changes in respiration characteristics in response to an aircraft are not obvious to an observer watching the animals, but quantitative analyses provide evidence of effects. During the four altitude experiments (Table 4), a decrease in the mean interval between blows was the strongest response, and the only consistent one, recorded when the aircraft descended. This tendency was not evident in the pooled data exclusive of the experiments or in the small samples of data collected in the presence and absence of a circling aircraft. The discrepancy may reflect the greater sensitivity of our controlled tests, in which whales were observed continuously while different treatments were applied, as opposed to comparisons involving pooled data gathered from many different whales over a number of days. Sample sizes for blow intervals were considerably larger than for any other variable, and this variable was measurable in more situations than any other.

No clear effects of the aircraft on number of blows per surfacing or blow rates were evident. Trends in the number of blows per surfacing relative to presence or altitude of aircraft were inconsistent between experiments and across observation techniques. The requirement for complete information about both a surfacing and dive before the blow rate could be calculated resulted in insufficient data for broad comparisons, though data from a single whale indicated an increase in blow rates after the descent of the aircraft.

Movement of whales out of an area as a response to a circling aircraft is difficult to define. As described earlier, there was one occasion in 1982 when we suspected that whales were dispersing in response to the circling aircraft (19 August 1982). However, during 1982 concentrations of whales were more difficult to find than in previous years. Socializing and echelon feeding, two behavior patterns that tended to maintain concentrations of whales in 1980 and 1981, were much less evident or absent in 1982 (Würsig et al. 1983). Dispersal of whales in possible response to the aircraft was noticed only once in 1980-81 (Fraker et al. 1982).

Considering observations during all three years of study (1980-82), decreases in blow intervals, hasty dives, and possibly decreases in the durations of surfacings appeared to be the best-supported and most consistent responses to the aircraft. In general, these responses were conspicuous if the aircraft approached or circled at 305 m a.s.l., occasional but not major at 457 m, and undetectable at 610 m. Clear effects of the aircraft on number of blows per surfacing, dive durations, blow rates, incidence of turning, frequency of aerial behaviors, and dispersal of whales were not evident, but in many cases sample sizes were too small to permit adequate analysis. Additional observations from a drifting vessel prior to the arrival of the aircraft and following its departure, and additional aircraft altitude experiments beginning at a control altitude of 610 m or more, would be helpful in elucidating the responses of the whales. Continuous observations of identifiable individuals through the various phases of the altitude experiments would allow examination of temporal patterns of responses. From this, the duration of responses might be determined.

Richardson et al. (1983b) concluded that the sensitivity of bowheads to aircraft seems quite variable and may depend on behavioral state or the presence of calves. Despite the above-reported reactions to the aircraft when it approached at 305 m a.s.l., Fraker et al. (1982) reported no obvious response by a group of feeding bowheads circled at 305 m for 30 min. Similarly, in August 1981, LGL personnel in a Twin Otter aircraft observed a group of apparently mating bowheads; gradual descents from 457 m to 152 m did not cause any apparent changes in behavior. Ljungblad et al. (1980) reported seasonal differences in responses of bowheads migrating off west and north Alaska. In the spring, bowheads usually dove in response to an aircraft surveying at 30-305 m altitude. In the fall they tended to remain on the surface even during extended periods of circling by the aircraft (however, mother-calf pairs tended to dive soon after being sighted during the fall). Ljungblad (1981) believed that bowheads observed south of the Bering Strait in spring were less sensitive to aircraft than were those near Barrow, and Ljungblad et al. (1982) found further evidence of lack of sensitivity south of Bering Strait. However, Marquette et al. (1982) suggested that bowheads near Barrow in spring rarely 'reacted in a negative manner' to an Aerocommander aircraft flying as low as 75 m a.s.l.

W.R. Koski (LGL Ltd., pers. comm.) found that eastern Canadian arctic bowheads overflown by a Twin Otter turboprop aircraft at 90 m a.s.l. altitude almost always dove, but the first pass at 150 m did not always elicit such a response. Shallenberger (1978) reported that some humpback whales off Hawaii were disturbed by aircraft at 305 m, while others showed no apparent response to aircraft at 152 m. Kaufman and Wood (1981) stated without details that 'No effects of low-flying aircraft on [humpback] whale behavior or usage of the area [in Hawaiian waters] could be discerned even though numerous aircraft were observed in the area'. Watkins and Schevill (1979) and Payne et al. (1981) have had success watching baleen whale behavior from light single-engine aircraft at altitudes of 50-300 m and 100 m, respectively.

There are few accounts and no detailed studies of baleen whale responses to helicopter disturbance. In one instance, gray whales in lagoons in Baja California were intentionally herded into shallow water by a helicopter attempting aerial photography, and some of the whales 'churned the water with flukes and fins until their wakes became churning cauldrons of foam' (Walker 1949, cited in Reeves 1977). Humpback whales off Labrador that had been actively investigating a large sailing vessel began spy-hopping as well as tail and flipper slapping when a helicopter hovered above them (J. Hickie, LGL Ltd., pers. comm.). Dahlheim (1981) found that bowheads rarely were disturbed by two Sikorsky H52-A helicopters at 142-228 m a.s.l. during the spring. Berzin and Doroshenko (1981) indicated that some bowheads in the Sea of Okhotsk during August paid 'no attention' to a large, turbine-powered MI-8 helicopter circling at low altitude and speed, while other whales dove upon first approach.

When bowheads react to aircraft, they are probably responding to aircraft noise, although vision may sometimes be involved. Though observations of responses of bowheads to helicopters have not been possible, Greene (1982) found that twin-engine Bell 212 helicopters, a type frequently used in offshore areas, produced underwater noise more intense than noise from either Islander or Twin Otter fixed-wing aircraft. Thus, reactions of bowheads to such a helicopter would probably be stronger than those to the Islander.

Observations from a fixed-wing aircraft circling overhead are useful in characterizing responses to aircraft and assessing relative responses to aircraft at different altitudes. However, most of the concern about possible effects of aircraft traffic in support of offshore oil exploration involves helicopters engaged in straight-line trips over the sea. During straight-line passes by a Bell 212 helicopter at 152-610 m a.s.l., helicopter sound was detectable in water for only 16-27 s, and was strong for only a few seconds (Greene 1982). These observations were obtained at 9 m depth directly below the flight path in comparatively shallow water (25 m) on a relatively calm day. The noise probably would be detectable for an even briefer period when the sea state was higher or the water depth greater (Urick 1972; Greene 1982). Also, newer helicopter designs with more than two rotor blades are less noisy than a Bell 212. Based on this information and our observations from an aircraft circling over the whales for a prolonged period, it seems doubtful that a single pass by a helicopter would elicit a very prolonged reaction by bowhead whales, although it often would elicit a hasty dive.

REACTIONS OF BOWHEADS TO SEISMIC EXPLORATION

Geophysical exploration by impulses of sound (hereafter called seismic exploration) produces sounds with source levels that greatly exceed those of other routine activities associated with offshore oil and gas exploration or production (Acoustical Society of America 1981; Greene 1982, 1983). Nowadays, arrays of airguns are the high energy sources most commonly used in offshore seismic exploration during open water periods. Such arrays typically have source levels of 245-250 dB//1 μPa at 1 m (Johnston and Cain 1981). However, other impulsive sources such as sleeve exploders and gas guns are occasionally used. Waterborne sound from any of these types of high-energy sources can often be detected at horizontal ranges of several tens of kilometres, even in shallow water where sounds are often rapidly attenuated (Ljungblad et al. 1980; Greene 1982, 1983). High explosives, which can produce even more intense and instantaneous sounds, are now rarely used in North American waters (Brooks 1981; Johnston and Cain 1981).

We have previously reported detailed observations of the behavior of bowheads seen 13 km from a seismic ship on 21 August 1980, and 6-8 km from the same ship on 25 August 1981 (Fraker et al. 1982). Noise levels near the whales were about 141 and 150 dB//1 μPa, respectively. The whales did not move away from the ship, and quantitative analysis provided no clear evidence that their behavior was unusual. We have also described two small-scale controlled experiments in which we fired a single airgun near bowheads in order to simulate, at least approximately, the noise from a full-scale seismic operation at greater distances. There was some indication of reduced durations of surfacing and reduced numbers of respirations per surfacing during the periods with airgun noise (but see additional analysis of these data, below). In addition, the whales stopped calling during one of these experiments.

Besides our previous observations, Ljungblad et al. (1980, pers. comm.) and Reeves and Ljungblad (1983) have seen bowheads near active seismic ships in the Alaskan Beaufort Sea in autumn. They did not notice any avoidance of the ships, but on one or two occasions they did see whales aggregating into unusually close groups in the presence of seismic noise. For a review of the limited available information about reactions of other species of marine mammals to seismic noise, see Richardson et al. (1983b).

In our 1982 program, observations of bowhead behavior in the presence of seismic noise were to be obtained on an opportunistic basis, but other subjects had priority for experimental work. We observed bowheads in the presence of seismic noise on four occasions in August 1982. In addition, we describe here two previously unreported sets of observations from 1980-81. Also, for completeness and consistency we reanalyze and summarize the 1980-81 data that we previously reported; new criteria for acceptance of data developed in 1982 are also applied to the 1980-81 data in these reanalyses.

Methods

Opportunistic Observations with Seismic Noise, 1982

On four dates in August 1982, we observed bowhead behavior when the seismic vessel 'GSI Mariner' was close enough to ensonify the water around the whales. The 36-m 'GSI Mariner' was using an array of 27 airguns of various size from 10 to 100 cu in and totalling 1410 cu in, or 23 L (J. Stone, GSI, pers. comm.). The interval between successive shots is typically 13-16 s, depending on the forward speed of the vessel and the desired spacing of shot points. The source level of this array is 38 bar-m, peak to peak (G. Bartlett, GSI, pers. comm.), or 246 dB//1 μPa referred to 1 m.

On 1 August we observed a whale that was well offshore as the seismic ship approached from the southwest. The range decreased from 39 to 24 km during the 1.5 h period of observations. No sonobuoy was deployed at this time, but we are confident that seismic sounds were present near the whales because the range was less and the water depth greater than on the other three occasions when sounds were monitored (see Table 11).

On 7 August we observed several whales, again well offshore, as the ship travelled northeast, generally toward the whales. The range decreased from 49 to 40 km as we watched, and a sonobuoy deployed near the whales detected the seismic noise. After leaving these whales, we collected a few

Table 11. Observations of bowhead whales in the presence of noise from seismic exploration, Canadian Beaufort Sea, August 1980-82.

Date	20 Aug '80	21 Aug '80	5 Aug '81	25 Aug '81	1 Aug '82	7 Aug '82	16 Aug '82	18 Aug '82
Location - N Lat.	69°53'	-	70°41'	69°52'	70°19'	70°19'	69°45'	69°36'
W Long.	133°03'	-	135°06'	134°50'	138°00'	137°01'	138°05'	138°22'
Water Depth (m)	12	12-13	68	11	300	65	150	125
Aircraft Altitude (m)	610	610	457-610	610	457	457	457	457
Seismic Sounds								
Vessel	Arctic Surv.	Arctic Surv.	E.O. Vetter	Arctic Surv.	GSI Mariner	GSI Mariner	GSI Mariner	GSI Mariner
Range (km)	c. 8	13	45-54	6-8	39-24	49-40	54-58	73-62
Bearing[a]	W	WSW	SW	E	SW	SSW	N-NE	NE-NNE
Received Level[b]	NR (est. 150 dB)	est. 141 dB	117 dB	est. 150 dB	NR	107-113 dB	127-132 dB	<125-133 dB
Ambient Level[b,c]	NR	-	87-96 dB	95-103 dB	NR	92-94 dB	99-102 dB	93-102 dB
Activity of Whales	Some mud churned up	Socializing	Socializing; defecating	Mud from mouths; social activity; log play	Log play	Swimming westward	Stationary or slow travel; some socializing; possible nursing	Slow to rapid travel; some aerial activity and socializing

[a] Bearing from whales to ship; e.g., on 20 Aug '80, the ship was 8 km west of the whales.
[b] Levels are in dB//1 μPa. NR = Not recorded. Estimates are based on range and Greene's (1982, p. 317) equation for received level vs. range for this ship.
[c] Ambient levels are for the 10-500 Hz band. They were for sounds recorded between seismic pulses.

observations of different whales 45 km from the ship and in deeper water (about 300 m depth; location 70°25'N, 136°50'W).

On 16 August we observed whales closer to shore but in fairly deep water northeast of Herschel Island. The seismic ship was farther offshore, moving east in an area north and then northeast of the whales. The range changed only slightly, from 54-58 km, during the course of the observations. A sonobuoy and a hydrophone deployed from the 'Sequel' at the whales' location both detected strong seismic impulses. We monitored whale behavior in the presence of these sounds for 1.5 h as 'Sequel' drifted quietly nearby, and then conducted a boat disturbance experiment in the presence of seismic sounds (see 'Reactions to Boats' section, above).

On 18 August we observed whales east of Herschel Island in the same general area as on the 16th. The seismic ship was moving west far to the NE-NNE of the whales. The range diminished from 73 to 62 km during the period of observation. The received level of the seismic sounds, again recorded via both sonobuoy and hydrophone, increased considerably over this period. We conducted a drilling noise playback experiment after an initial 2.5-h period of monitoring behavior in the presence of seismic sounds with 'Sequel' drifting quietly nearby.

Observations with Seismic and Airgun Noise, 1980-81

We have previously described our observations near the seismic ship 'Arctic Surveyor' on 21 August 1980 and 25 August 1981 (Fraker et al. 1982). In 1980-81 this vessel used four sets of three large sleeve exploders as the source of noise impulses. The circumstances of the observations are summarized in Table 11. We have also described the circumstances and results of our two small-scale controlled experiments with a single airgun fired near whales on 18 and 19 August 1981. Fraker et al. give more details concerning both the opportunistic observations near the 'Arctic Surveyor' and the experiments with the airgun. Greene (1982) describes the characteristics of the seismic sounds from that ship and the airgun. Peak levels of airgun noise received near the whales were $\geq$123 dB and $\geq$118 dB during the 5 and 3 km experiments, respectively. Ambient levels between airgun pulses were 89-98 dB and 97-100 dB in the 10-500 Hz band (Greene, pers. comm.)

In addition, from 11:52 to 13:38 MDT on 20 August 1980, we observed whales in shallow water (12 m) about 8 km from the 'Arctic Surveyor' (Table 11). Because no sonobuoy was deployed near the whales, we excluded these observations from both the 'normal behavior' and the 'behavior near seismic exploration' sections of our 1980-81 report. However, the operator of the ship confirms that it was 'shooting' seismic surveys at the time. Because of the close range, it can be assumed that the whales were exposed to intense seismic sounds. Greene (1982) found that the received level from this ship at 8 km range in shallow water was about 150 dB//1 μPa. Therefore, we include the observations here as a case of behavior in the presence of seismic noise.

On 5 August 1981, we observed whales well offshore and, via sonobuoy, recorded seismic impulses near the whales. These observations were also excluded from our 1980-81 analysis of 'normal behavior'; they were not further discussed because we had not been able to identify the source of the seismic signals. We now know that they came from the GSI vessel 'E.O. Vetter', which was using an airgun array 45-54 km SW of the location of the whales. The 'Vetter' is a larger ship than the 'GSI Mariner'; it is 56 m long and can deploy a larger airgun array with total gun volume about 2000 cu in, or 33 L (J. Stone and K. Bottomly, GSI, pers. comm.).

Collection and Analysis of Behavioral Observations

Observations in the presence of seismic sounds were obtained following our usual procedures. The observation aircraft was always at an altitude of either 457 or 610 m a.s.l. (Table 11). Whenever possible, a sonobuoy was deployed near the whales.

In analyzing the quantitative information on surfacings, respirations and dives, we have excluded calves (whales <1 yr old), whose normal behavior often differs noticeably from that of adults (Würsig et al. 1983). As noted in 'General Methods' we now include in the analysis a few dive times whose start or end times may have been imprecisely determined, provided that the overall duration could not have been miscalculated by more than 5%. Besides applying these altered criteria to the new 1982 data, we have used this approach in reanalyzing our 1980-81 data. These changes, along with some corrections to the 1980-81 data files, are responsible for differences between results reported below vs. corresponding results reported by Fraker et al. (1982).

Results for the various observations of whales near seismic vessels are presented separately. Each case is compared with behavior in situations that were similar except for the absence of potential disturbance. There is much day-to-day variation in the behavior of summering bowheads. In the absence of control data collected just before the seismic noise begins, this natural variability makes it difficult to determine whether seismic noise or some other factor is responsible for apparent changes in behavior. The best available approach for assessing opportunistic observations in the presence of seismic noise appears to be to compare them with 'presumably undisturbed' observations collected in the most similar conditions possible. If similar trends emerged in many such comparisons, one could conclude that seismic noise does have a more or less consistent effect. This approach is followed here.

An overall statistical comparison of the seismic present vs. seismic absent conditions is desirable, but not straightforward when the various incidents need to be treated separately. One approach is to use one of the available methods for pooling the results of several independent statistical tests (Rosenthal 1978). That approach is conceptually the same as, but more flexible than, a 2-way analysis of variance with one treatment factor (seismic vs. no seismic) and one blocking factor (incident 1, 2, ...). For comparison, we also present simple comparisons of all data collected in the presence of seismic noise vs. all 'presumably undisturbed' data; however, we consider the 'pooled probabilities' approach to be more appropriate.

Results

Opportunistic Observations in 1982

1 August 1982. -- The one whale observed in detail on this date was 39 km from the approaching 'GSI Mariner' when we began observing, and 24 km away when we left 1.5 h later. The 'Mariner' was firing its airgun array at the time, but no sonobuoy was deployed to record sounds near the whales. Throughout this period the whale remained in sight at or very near the surface, and played continuously with a large log. This case is described in detail in Würsig et al. (1983). We have seen such behavior in the past both in the presence of seismic noise (25 August 1981) and in cases when we have no information about seismic vessels being nearby. The usual measurements of surface times, dive times and respiration rates are not meaningful for a whale remaining continuously at the surface.

There was no evidence that the behavior of this whale was influenced by the assumed presence of seismic noise. However, by remaining at or near the surface, a whale could substantially reduce the received level of seismic sounds. Received level decreases with decreasing depth because sound pressure is 'released' at the air-water interface. This pressure release effect is significant at depths shallower than about 1/2 the wavelength of the sound (C.R. Greene, pers. comm.). For a 150 Hz sound, the wavelength is 10 m, so received level would be reduced when the whale was within 5 m of the surface. For this reason, it is very likely that the whale observed at the surface on 1 August 1982 was not receiving seismic impulses at the same intensity as occurred at greater depths. Whether it had, before our arrival, been diving to depths where more intense noise would be received is unknown.

7 August 1982. -- The 6 or 7 whales that we observed near a sonobuoy 49-40 km ahead of the approaching 'GSI Mariner' were swimming consistently westward at moderate or greater speed. The seismic sound level received by the sonobuoy (hydrophone depth 18 m) was about 107 dB//1 μPa when the ship was 47 km away, and increased to 113 dB at range 40 km. These are comparatively low received levels; the ambient level between seismic pulses was 92-94 dB in the 10-500 Hz band (Table 11; sound levels from C.R. Greene, pers. comm.). Because the ship was travelling northeast and was situated south-southwest of the whales, the westbound whales were remaining at about the same distance from the ship. To travel directly away from the ship, they would have had to move north, not west. However, their westward course took them away from the projected track of the ship--i.e., away from the anticipated closest point of approach of the ship.

Two whales observed briefly farther offshore and about 45 km ahead of the approaching seismic ship were also travelling west-southwest and west, generally away from the projected track of the ship but not away from the ship itself.

It is probable, although not certain, that the westward movement of both groups of whales was unrelated to the presence of the seismic vessel. Whales seen in that general area under presumably undisturbed conditions on 6 August were also moving west. The overall distribution of whales in the central Beaufort Sea seemed to be shifting westward during early August (Richardson et al. 1983a).

Durations of surfacings, durations of dives, and blow intervals of bowheads observed in the presence of seismic noise on 7 August were all significantly lower than for all whales observed under presumably undisturbed conditions in August 1982 (Table 12 and Fig. 7; see Table 13 for summarized data and Table 14 for details of statistical tests). The number of blows per surfacing was not significantly different. However, most of the 'presumably undisturbed' data were collected later in the month when the whales were not actively travelling west. Too few data on 'presumably undisturbed' travelling whales were collected to allow a comparison restricted to travelling animals. Thus, in this instance it is uncertain whether the differences in behavior can be attributed to the presence of seismic noise or to other factors.

16 August 1982. -- On this date, we maneuvered the MV 'Sequel' into an area where several whales were alternately surfacing and diving, either remaining in the same locations or travelling slowly, with some socializing and possible nursing of calves. Seismic noise from the 'GSI Mariner', located some 54-58 km farther offshore, was detectable throughout the observations. Seismic noise levels were 127-132 dB//1 μPa, about 20 dB higher than on 7 August (Table 11). The data discussed here were obtained from adult whales near 'Sequel' as she drifted quietly and the observation aircraft circled at 457 m a.s.l. overhead. We exclude data collected in the first half hour after the boat motor stopped, and data collected during a subsequent boat disturbance experiment.

Table 12. Summary of statistical comparisons of surfacing, respiration and dive characteristics of non-calf bowheads in the presence and absence of seismic noise[a].

Circumstances Compared		Seismic Sound		Variable			
Seismic	'Control'	Source	Received Level (dB//1 μPa)	Blows/ Surfacing	Surface Time	Blow Interval	Dive Time
Sleeve Exploders							
20 Aug 80	20 + 22 Aug 80	8 km from Arctic Surveyor	c. 150	NS	++	+	(+)
21 Aug 80	20 + 22 Aug 80	13 km from Arctic Surveyor	c. 141	NS	NS	NS	
25 Aug 81	All in <16 m	6-8 km from Arctic Surveyor	c. 150	NS	NS	(-)	NS
Airgun Array							
5 Aug 81	6-13 Aug 81	45-54 km from Vetter	117	NS	NS	NS	NS
7 Aug 82	All 1982	49-40 km from GSI Mariner	107-113	NS	-	--	-
16 Aug 82	14-19 Aug 82	54-58 km from GSI Mariner	127-132	--	-	+	(-)
18 Aug 82	14-19 Aug 82	73-62 km from GSI Mariner	<125-133	-	-	++	-
Single Airgun							
18 Aug 81 vs.	Pre & Post Airgun	One gun @ 5 km	≥123	(-)	NS	NS	NS
19 Aug 81 vs.	Pre & Post Airgun	One gun @ 3 km	≥118	NS	NS	+	
Overall							
All full-scale	All 'control'	Sleeve exploders, array		--[b]	---	NS	NS
All full-scale	Paired 'control'	Sleeve exploders, array		(-)[c]	(-)	NS	(-)
All	Paired 'control'	All		-[c]	-	+	(-)

[a] See Table 13 for summarized data and Table 14 for details of the tests. Test results are coded as
NS if $p > 0.1$,
(+) if mean value higher with than without seismic noise, and $0.1 \geq p > 0.05$,
(-) if mean value lower with than without seismic noise, and $0.1 \geq p > 0.05$,
\+ or - if $0.05 \geq p > 0.01$,
++ or -- if $0.01 \geq p > 0.001$,
+++ or --- if $p \leq 0.001$.

[b] Based on simple pooling of all 1980-82 data. See text for discussion of the appropriateness of this approach.

[c] Based on the 'unweighted z' method of pooling the results of the individual comparisons (Rosenthal 1978).

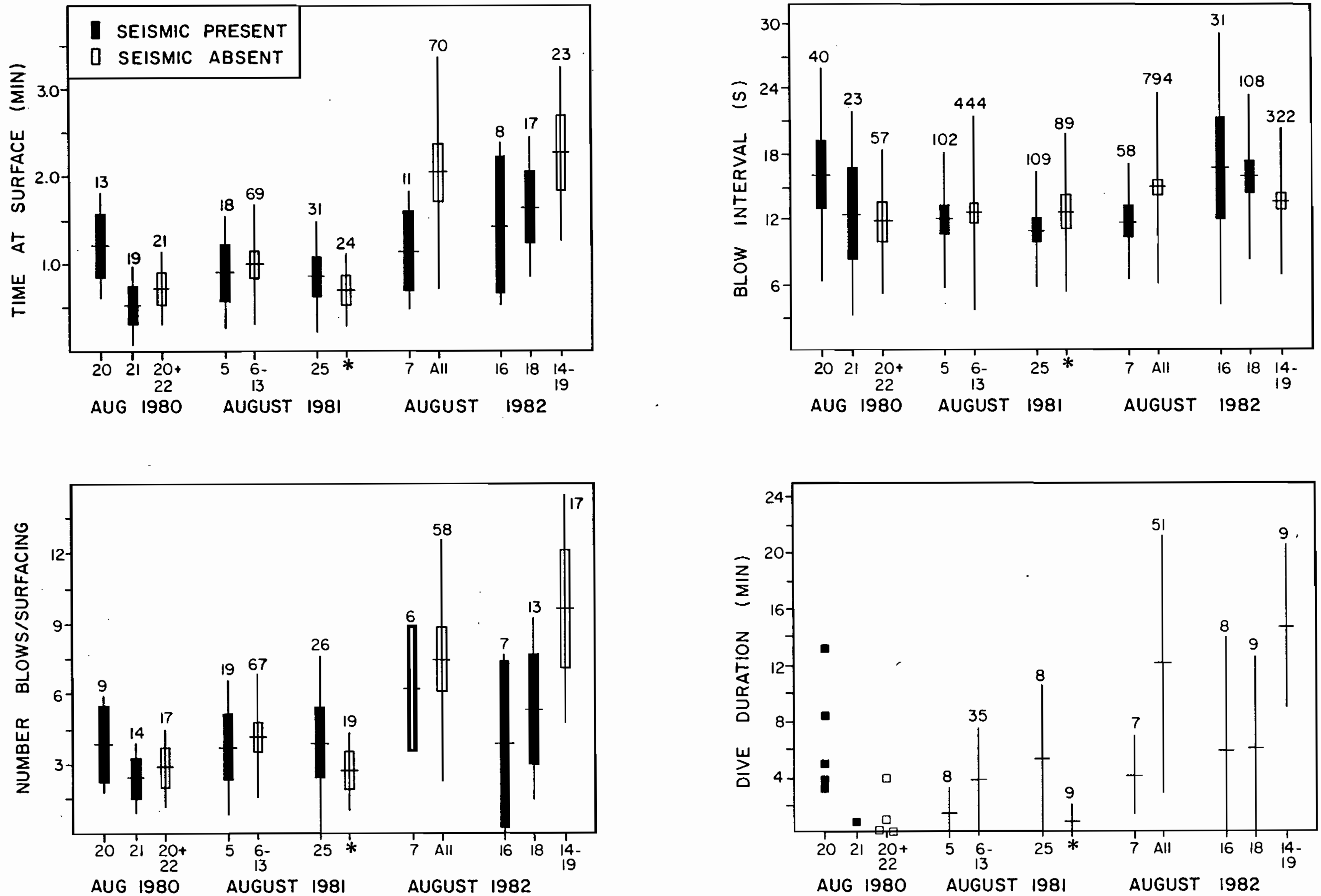


FIGURE 7. Surfacing, respiration and dive characteristics of bowheads observed in the presence and absence of seismic noise, 1980-82. The 'seismic absent' results are from 'presumbably undisturbed' whales observed in situations similar to those when the corresponding 'seismic present' data were collected. Calves are excluded. Presentation as in Figure 3.

Table 13. Surfacing, respiration and dive characteristics of non-calf bowheads observed in the presence and absence of seismic noise.

Date (s)	Seismic Source	Mean	s.d.	n	Mean	s.d.	n
		Blows/Surfacing			Duration of Surfacing (min)		
20 Aug 1980*	8 km from Ar. Surv.	3.89	2.09	9	1.23	0.592	13
21 Aug 1980	13 km from Ar. Surv.	2.43	1.45	14	0.54	0.438	19
20 + 22 Aug 1980	-	2.88	1.65	17	0.73	0.414	21
5 Aug 1981	45-54 km from Vetter	3.74	2.86	19	0.91	0.645	18
6-13 Aug 1981	-	4.16	2.64	67	1.00	0.673	69
25 Aug 1981	6-8 km from Ar. Surv.	3.92	3.65	26	0.86	0.630	31
All in <16 m	-	2.68	1.67	19	0.70	0.403	24
7 Aug 1982	40-49 km from GSI Mar.	6.17	2.56	6	1.16	0.675	11
All 1982	-	7.43	5.11	58	2.05	1.320	70
16 Aug 1982	54-58 km from GSI Mar.	3.86	3.81	7	1.45	0.924	8
18 Aug 1982	62-73 km from GSI Mar.	5.31	3.84	13	1.65	0.785	17
14-19 Aug 1982	-	9.59	4.80	17	2.27	0.985	23
All cases with seismic, 1980-82		3.71	3.03	119	0.95	0.720	146
All 'presumably undisturbed', 1980-82		4.90	3.61	322	1.30	0.960	368
		Blow Interval (s)			Dive Duration (min)		
20 Aug 1980*	8 km from Ar. Surv.	16.08	9.688	40	6.70	4.135	5
21 Aug 1980	13 km from Ar. Surv.	12.57	9.283	23	0.87	-	1
20 + 22 Aug 1980	-	11.82	6.563	57	1.34	1.792	4
5 Aug 1981	45-54 km from Vetter	12.05	6.170	102	1.41	1.786	8
6-13 Aug 1981	-	12.62	8.837	444	3.74	3.706	35
25 Aug 1981	6-8 km from Ar. Surv.	11.04	5.263	109	5.27	5.162	8
All in <16 m	-	12.64	7.131	89	0.76	1.236	9
7 Aug 1982	40-49 km from GSI Mar.	11.78	5.265	58	4.15	2.772	7
All 1982	-	14.86	8.660	794	12.08	9.153	51
16 Aug 1982	54-58 km from GSI Mar.	16.58	12.487	31	5.94	7.994	8
18 Aug 1982	62-73 km from GSI Mar.	15.85	7.559	108	6.10	6.418	9
14-19 Aug 1982	-	13.61	6.719	322	14.69	5.741	9
All cases with seismic, 1980-82		13.14	7.324	547	4.00	4.829	62
All 'presumably undisturbed', 1980-82		13.46	8.464	2822	6.26	7.648	156

* Arctic Surveyor was shooting seismic, but no sonobuoy was deployed to confirm presence of seismic noise in water near whales.

Table 14. Statistical comparisons of surfacing, respiration, and dive characteristics of non-calf bowheads in the presence and absence of seismic noise. Plus signs indicate that the mean value was greater when seismic noise was present; minus signs indicate that the mean was greater when seismic noise was absent.

Parameter	Cases of Full-Scale Seismic Exploration							Airgun Experiments		Pooled*	
Date with Seismic Control Data Range from Source Source Identity	20 Aug '80 20 + 22 Aug '80 8 km Arctic Surveyor	21 Aug '80 20 + 22 Aug '80 13 km Arctic Surveyor	5 Aug '81 6-13 Aug '81 45-54 km Vetter	25 Aug '81 All in <16 m 6-8 km Arctic Surveyor	7 Aug '82 All '82 49-40 km GSI Mariner	16 Aug '82 14-19 Aug '82 54-58 km GSI Mariner	18 Aug '82 14-19 Aug '82 73-62 km GSI Mariner	18 Aug '81 Pre/Post 5 km 1 airgun	19 Aug '81 Pre/Post 2.5-3.5 km 1 airgun	Full-scale	All
Blows/Surfacing											
Type of Test	t	t	t	t	t	t	t	Kr-Wal	Kr-Wal		
Test Statistic	+1.35	-0.80	-0.61	+1.38	-0.59	-2.80	-2.63	H = -4.65	H = -2.02		
df	24	29	84	43	62	22	28	2	2		
Probability**	+0.19	-0.43	-0.54	+0.17	-0.56	-0.010	-0.014	-0.096	-0.36	-0.10	-0.021
z	+1.31	-0.79	-0.61	+1.37	-0.58	-2.58	-2.46	-1.66	-0.92	-1.64	-2.31
Surface Time											
Type of Test	t	t	t	t	t	t	t	Kr-Wal	Kr-Wal		
Test Statistic	+2.90	-1.41	-0.56	+1.08	-2.18	-2.06	-2.14	H = -4.17	H = -1.75		
df	32	38	85	53	79	29	38	2	2		
Probability	+0.007	-0.17	-0.58	+0.28	-0.032	-0.048	-0.039	-0.12	-0.41	-0.10	-0.026
z	+2.70	-1.37	-0.55	+1.08	-2.14	-1.98	-2.06	-1.56	-0.82	-1.63	-2.23
Blow Interval											
Type of Test	t	t	t	t	t	t	t	ANOVA	ANOVA		
Test Statistic	+2.58	+0.41	-0.62	-1.82	-2.67	+2.14	+2.90	F = +1.53	F = +4.22		
df	95	78	544	196	850	351	428	2, 115	2, 183		
Probability	+0.011	+0.68	-0.54	-0.070	-0.008	+0.033	+0.004	+0.22	+0.016	+0.28	+0.029
z	+2.54	+0.41	-0.61	-1.81	-2.65	+2.13	+2.88	+1.23	+2.41	+1.09	+2.18
Dive Time											
Type of Test	M-W U		M-W U	M-W U	M-W U	M-W U	M-W U	Kr-Wal			
Test Statistic	U = +2		z = -1.34	U = +27	z = -2.14	U = -16	U = -17	H = -0.16			
n	5,4	1,4	8, 35	8, 9	7, 51	8, 9	9, 9	df = 2	***		
Probability	+0.064		-0.18	+0.4	-0.032	-0.07	-0.05	-0.93		-0.063	-0.078
z	+1.85		-1.34	+0.84	-2.14	-1.81	-1.96	-0.09		-1.86	-1.76

* Pooled probability and z are from the 'unweighted z' method (Rosenthal 1978); z is the normal (0,1) statistic.
** 2-sided probability.
*** N = 0 during airgun firing on 19 Aug '81.

The whales were not oriented consistently in any one direction, and were not travelling away from the seismic vessel. Observers in the aircraft noticed nothing unusual about the behavior of the animals. However, quantitative analysis showed that the surface times, number of blows per surfacing, and dive times averaged lower than in the same area under presumably undisturbed conditions on 14-19 August (Table 12; Fig. 7). Blow intervals were significantly longer than on 14-19 August, contrary to the trend on 7 August.

18 August 1982. -- On this date we again observed whales in the presence of seismic noise from the 'GSI Mariner'. Here we consider only the data from non-calves observed before we began a drilling noise playback experiment. The distance from the ship decreased from 73 to 62 km during the period of observation. Seismic sound levels increased from barely detectable at the start of observations to 125 dB//1 μPa mid way through the period and 133 dB at the end.

The whales were often travelling, although not in any consistent direction. The observers noted nothing unusual about their behavior. However, detailed analysis again showed increased blow intervals and reduced surface times, number of blows per surfacing, and dive times relative to those under presumably undisturbed conditions on 14-19 August ($p<0.05$ in each case; Table 12; Fig. 7).

Opportunistic Observations in 1980-81

5 August 1981. -- Several bowheads were observed socializing and apparently feeding some 45-54 km from the 'E.O. Vetter', a ship using an airgun array. Seismic sounds with level 117 dB//1 μPa were detected via sonobuoy near the whales. The observers in the aircraft noticed no unusual behavior, and numerical analysis indicated that surfacing, dive and respiration characteristics were similar to those of 'presumably undisturbed' whales seen on 6-13 August 1981 (Table 12; Fig. 7).

20 August 1980. -- Whales were observed in shallow water about 8 km from the 'Arctic Surveyor', a seismic ship that was using sleeve exploders at the time. Table 12 and Figure 7 show that, contrary to the observations in 1982, surface times were significantly longer ($p<0.01$) and dive times marginally longer ($p<0.1$) than for 'presumably undisturbed' whales in the same area on 20 and 22 August 1980. The number of blows per surfacing was not significantly different in the two situations. As was sometimes found in 1981-82, the blow intervals were longer in the presence of seismic noise ($p<0.05$).

21 August 1980 and 25 August 1981. -- We have previously described two observations of bowheads at distances of 13 km and 6-8 km from the 'Arctic Surveyor' while it was using sleeve exploders (Fraker et al. 1982). Sonobuoys recorded strong seismic signals near the whales; estimated seismic noise levels there were 141 and 150 dB//1 μPa, respectively. In neither case was there any clear indication of altered behavior, either as judged by the observers in the aircraft or from detailed quantitative analysis. Table 12 and Figure 7 summarize our reanalyses of these data, based on the same analysis procedures as applied to 1982 data. The interpretation is as previously reported: no clear evidence of differences from the most appropriate set of 'presumably undisturbed' data.

Airgun Experiments 1981

The circumstances and results of two controlled experiments with a 40 cu in airgun were described in Fraker et al. (1982). In the two experiments, the airgun was deployed from the 'Sequel' about 5 km and 3 km, respectively, from groups of whales. After a period of control observations of 'presumably undisturbed' whales, the airgun was fired every 10 s for about 20 min. Noise from the one airgun 5 km from whales was estimated to be similar in level to that 20 km from a full-scale airgun array.

As reported by Fraker et al., during the period of airgun noise the whales continued their previous activity--echelon feeding on one occasion, and diving with gradual travel to the southwest on the other. During the 5 km experiment, there was evidence of reduced echelon sizes during the period of airgun noise, but echelon feeding did continue, and the whales did not leave the area. However, during the 5 km experiment the whales stopped calling for the 20 min period of airgun firing, and resumed thereafter.

During both experiments, the mean duration of surfacing and mean number of blows per surfacing were reduced during the period of airgun noise relative to the means before the airgun began to fire (Fig. 8). However, current procedures show these differences to be non-significant or, at most, only marginally significant (Table 12). During the 5 km experiment, dive durations tended to be less while the airgun was firing than they were before or after that period, but the sample size was small and the difference not statistically significant. No dive durations were recorded during the airgun phase of the 3 km experiment. During both experiments, blow intervals tended to be longer during the airgun firing phase than had been true previously. The difference was statistically significant in the 3 km experiment ($p<0.02$). The trends in these experimental results are generally consistent with our opportunistic observations during 1982 in the presence of noise from a full-scale airgun array. However, more of the trends were statistically significant in the 1982 results than in the single airgun experiments.

Overall Results on Surfacing, Respiration and Dives, 1980-82

Our previously reported results (Fraker et al. 1982) gave no indication that summering bowheads either move away from full-scale seismic ships or change their behavior when in the presence of strong seismic sounds. However, there were indications of behavioral responses to a single airgun firing nearby for 20 min.

Given the new data presented above, there is still no clear indication that bowheads attempt to swim away from seismic ships. However, there was evidence of altered surfacing, respiration and dive cycles in all 3 instances in 1982 when it was possible to do numerical analyses of behavior in the presence of seismic noise. In one additional case (1 August 1982), a whale under observation for 1.5 h did not dive, and thereby--whether intentionally or not--probably reduced the received level of the seismic noise. There was also evidence of altered surface times and blow intervals near a seismic ship on 20 August 1980. In this case, unlike the others, surface times were longer in the presence of the ship than under undisturbed conditions.

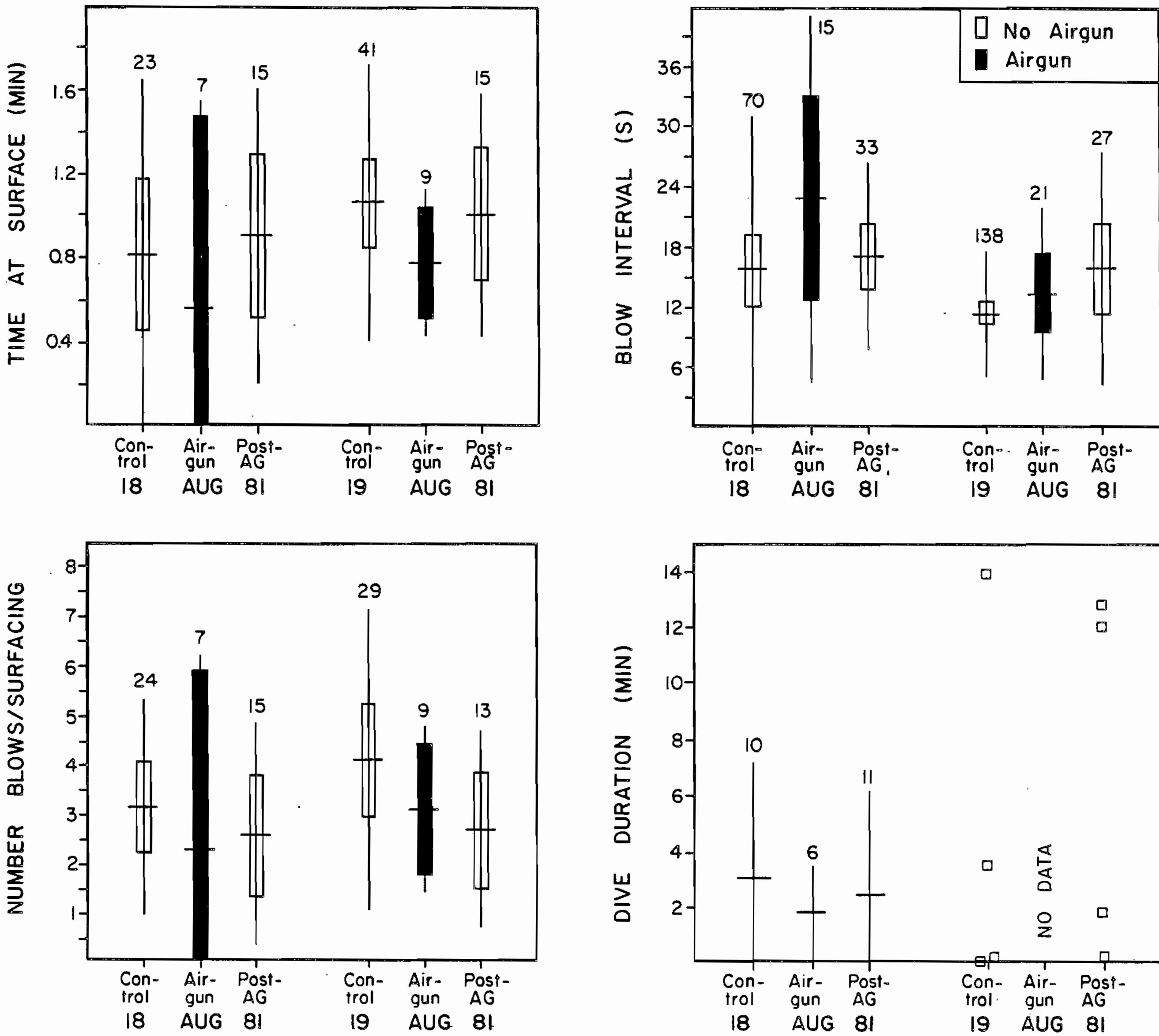


FIGURE 8. Surfacing, respiration and dive characteristics of bowheads observed before, during and after an airgun was fired. Airgun-whale distance was about 5 km on 18 August and 2.5-3.5 km on 19 August. Calves are excluded. Presentation as in Figure 3.

No one surfacing, respiration or dive variable was consistently different in the presence and absence of seismic noise (Table 12). However, the duration of surfacings, number of blows per surfacing and, to a lesser degree, the duration of dives, were usually lower in the presence of seismic noise than in the matched 'presumably undisturbed' conditions.

When all 1980-82 data in the presence of seismic noise were compared to all 'presumably undisturbed' data, number of blows per surfacing and duration of surfacing were found to be significantly lower in the presence of seismic noise (Table 12). Blow intervals and duration of dives were not significantly different. However, as noted above under Methods, these simple overall analyses are potentially confounded by day-to-day and year-to-year variability in behavior. We consider them to be of doubtful reliability.

By appropriate pooling of the statistical probabilities from the several individual incidents that we have studied, one can minimize these problems. The calculations are given in Table 14 and summarized in the last two lines of Table 12. Based only on the opportunistic observations near full-scale seismic ships, number of blows per surfacing, duration of surfacing, and duration of dive are marginally reduced in the presence of seismic noise ($0.1 \geq p > 0.05$ in each case). When the airgun experiments as well as the opportunistic observations are considered, the reduced number of blows per surfacing and duration of surfacing are significant at the $p < 0.05$ level, and the reduced duration of dives at the marginal $p < 0.1$ level. Also, there is evidence of longer blow intervals, on average, in the presence of seismic noise ($p < 0.05$).

The overall results concerning durations of surfacings and dives suggest that surfacing/dive cycles tend to be briefer in the presence of seismic noise. To test this, we compared lengths of such cycles on 16 and 18 August 1982 in the presence of seismic noise with data collected from the same area on 14-19 August 1982 in the absence of seismic noise. Cycles were significantly shorter with seismic noise (Table 15; $p < 0.05$). The proportion of each cycle spent at the surface, i.e. surface time divided by surface plus dive time, was greater in the presence of seismic noise, but not significantly so.

Table 15. Surface-dive cycles of non-calf bowheads in the presence and absence of seismic noise.

Date(s)	Seismic Source (- = None)	Mean	s.d.	n	Statistical Comparison[a]
Length of Surface + Dive Cycle (min)[b]					
16 + 18 Aug 82	'GSI Mariner'	6.91	7.180	13	U = 21; <0.05
14-19 Aug 82	-	15.96	6.905	8	
18 Aug 81	- (pre)	1.66	1.766	7	
18 Aug 81	One airgun	2.19	2.726	5	H = 1.61; >0.25
18 Aug 81	- (post)	3.69	4.027	9	
Proportion of Cycle at Surface[c]					
16 + 18 Aug 82	'GSI Mariner'	0.264	0.183	13	U = 32; >0.1
14-19 Aug 82	-	0.158	0.053	7	
18 Aug 81	- (pre)	0.174	0.097	4	
18 Aug 81	One airgun	0.231	0.201	3	H = 0.12; >0.9
18 Aug 81	- (post)	0.258	0.212	5	
Blow Rate (Blows/min)[d]					
16 + 18 Aug 82	'GSI Mariner'	0.970	0.718	12	t = 1.23; >0.1
14-19 Aug 82	-	0.559	0.247	5	
All 1982	'GSI Mariner'	0.952	0.662	14	t = 1.40; >0.1
All 1982	-	0.697	0.470	25	
All 1980-81	Various	1.243	1.077	17	t = 0.02; >>0.1
All 1980-81	-	1.238	1.113	46	

[a] U designates Mann-Whitney U-test, H designates Kruskal-Wallis test with df = 2, and t designate Student's t-test.
[b] Includes all cycles when durations of surfacing plus following dive were known.
[c] Duration of surfacing divided by duration of that surfacing plus following dive. Cycles with div duration <31 s are excluded.
[d] Number of respirations during a surfacing divided by duration of that surfacing plus followin dive. Cycles with dive duration <31 s are excluded.

The airgun experiments in 1981 were another situation when whales were observed under comparable conditions with and without seismic noise. No analysis of cycle lengths was possible for the 19 August 1981 experiment because no dive durations were recorded during the period of airgun firing. During the 18 August 1981 experiment, neither cycle length nor proportion of cycle at the surface differed significantly among the phases of the experiment (Table 15). The difference from the 1982 results may be related to the depth of diving. Whales were diving deeply in 1982, but on 18 August 1981 they were feeding just below the surface where received sound pressure levels would not be as intense as at deeper depths.

We found no evidence that blow rates differed in the presence and absence of seismic noise. Blow rate in blows per minute was calculated as number of respirations in a surfacing divided by length of that surfacing plus the following dive. There was no significant difference in blow rates with and without seismic noise (1) in the 14-19 August 1982 period near Herschel Island, (2) in 1982 overall, or (3) in 1980-81 overall (Table 15).

Other Behavioral Variables with and without Seismic Noise

Bowhead Calls. -- We recorded waterborne sounds near the whales on six occasions when we observed bowheads in the presence of noise from full-scale seismic exploration. On all six occasions, bowhead sounds of the usual types were recorded (Table 16; cf. Würsig et al. 1982, 1983 for description of sound types and frequency of occurrence in 'presumably undisturbed' conditions). It appears that the presence of pulses of seismic noise in the water normally does not cause bowheads to cease calling. In 1982, the average rate of loud calls (i.e. calls from whales near the sonobuoys) was only slightly lower in the presence of seismic noise than during presumably undisturbed conditions (with seismic, 4.5 calls/whale-h, n = 3, range 2.6-8.0; undisturbed, 7.5 $\pm$ s.d. 7.1 calls/whale-h, n = 14).

We also recorded underwater sounds near the whales during the two airgun experiments in August 1981. During the experiment at 3 km range, very few bowhead calls were heard before, during, or after the period of airgun firing (Table 16). During the experiment at 5 km range, however, the whales

Table 16. Numbers and types of bowhead sounds recorded in the presence of seismic noise, 1980-82[a].

Date	Observation Time (MDT)	General Activity	Level of Calls	Approx. No. Whales	Whale-h of Observation	# Sounds of Each Type								Calls per Whale-h
						Up	Down	Constant	Double or inflected	High	Harmonic	Pulsive	Total	
Sleeve Exploders														
21 Aug '80	19:35-20:35	-	All	7	7.0	17	6	1	3	9	3	31	70	10.0
25 Aug '81	11:25-12:38	Swimming, mild socializing	All	4-15	15.7	11	0	0	0	0	0	0	11	0.7
Airgun Array														
5 Aug '81	10:29-10:41	Swimming	All	5	1.0	5	0	0	0	2	0	6	13	13.0
7 Aug '82	10:15-11:06	Swimming	Loud	5	4.25	15	14	4	1	0	0	0	34	8.0
			All	-	-	66	70	25	11	4	0	8	184	-
16 Aug '82	15:25-16:30	Swimming, brief mild socializing	Loud	7	7.6	8	1	6	1	0	0	6	22	2.9
			All	-	-	101	32	24	19	2	2	19	199	-
18 Aug '82	16:38-18:00	Swimming, mild socializing	Loud	8[b]	10.9	11	1	10	2	0	2	2	28	2.6
			All	-	-	63	80	90	17	13	56	8	327	-
Single Airgun														
18 Aug ' 81	Pre-Airgun	Echelon feeding	All	20-30	36.7	4	3	0	0	0	1	3	11	0.3
	Airgun	Echelon feeding	All	20-30	8.3	0	0	0	0	0	0	0	0	0.0
	Post-Airgun	Echelon feeding	All	20-30	52.5	33	3	1	1	5	12	2	57	1.1
19 Aug '81	Pre-Airgun	Feeding, socializing	All	5-6	8.0	3	0	0	1	0	0	0	4	0.5
	Airgun	Mild socializing	All	5-6	1.7	1	0	0	0	0	0	0	0	0.6
	Post-Airgun	Mild socializing	All	4	3.2	1	0	0	0	0	0	0	1	0.3

[a] Data compiled by C.W. Clark.
[b] One gray whale also present.

apparently ceased calling during the period of airgun firing. After the airgun ceased firing, the calls were recorded at an even greater rate than during the pre-airgun phase.

Turning. -- If whales were distressed by seismic noise, it is possible that they might turn more frequently than normal. However, there was no evidence that this happened either near Herschel Island in mid August 1982 or in shallow water off the Tuktoyaktuk Peninsula on 20-22 August 1980:

Dates	Seismic Source	# Turns during Surfacing			Percent Surfacings with Turns
		None	One	>1	
16 + 18 Aug 82	'GSI Mariner'	24	4	3	23%
14-19 Aug 82	-	30	5	2	19
20-21 Aug 80	'Arctic Surveyor'	20	7	0	26
20 + 22 Aug 80	-	16	5	0	24

Speed of Movement. -- In the mid-August 1982 period, there was no evidence that the speed of movement was different on the two days with seismic noise than on other days in the 14-19 August period:

Dates	Seismic Source	Speed of Movement during Surfacing				
		None	Slow	Moderate	Fast	Changed
16 + 18 Aug 82	'GSI Mariner'	3	8	4	1	4
14-19 Aug 82	-	3	8	6	1	7

Speed was recorded too rarely in the 20-22 August 1980 period to warrant analysis.

Industry Sightings

Fraker et al. (1982) mention nine reports of a total of at least 20 whales sighted at ranges 2-7 km from the 'GSI Mariner' in 1981. Fraker et al. had no information about the activity of the ship at the times of these sightings. A subsequent search of GSI records indicated that seven of the sightings, involving at least 17 whales, were obtained while the ship was firing its airgun array (G. Bartlett, GSI, pers. comm.). In each of these seven cases, the airguns had been firing for at least 0.97 h before the whales were seen; estimated ranges were 2-7 km.

No new sightings of bowheads near seismic vessels were reported to us by industry personnel in 1982.

Discussion

Based on our limited data from 1980-81, Fraker et al. (1982) concluded that there was little evidence that full-scale seismic exploration at distances as close as several kilometres results in detectable behavioral effects on bowheads. However, there was evidence of briefer cycles of surfacing and diving in least one of the single airgun experiments done in 1981. Fraker et al. suggested that the apparent reaction to the airgun but not to full-scale seismic operations may have been a response to the sudden onset of the airgun noise. The observations in the presence of full-scale seismic noise were obtained when the noise had been present for a prolonged period before observations began.

We now have considerably more data concerning bowhead behavior in the presence of seismic noise, although all of the additional data come from opportunistic 'uncontrolled' observations. There is still no clear evidence that bowheads ever try to move away from seismic vessels present at ranges of several kilometres or more. In the presence of seismic noise, whales seem to engage in normal activities, including surfacing and diving, feeding, socializing, calling and sometimes travelling. Limited data indicate that their rates of turning and of travelling in the presence of seismic noise are similar to those in quiet conditions. However, we now have evidence that the surfacing, diving and respiration cycles of bowheads sometimes are altered in the presence of noise from distant seismic exploration.

The overall statistical analyses indicate that, in the presence of seismic noise, surface times and number of respirations per surfacing are significantly lower ($p<0.05$), durations of dives are marginally lower ($p<0.1$), and blow intervals are longer ($p<0.05$). However, on individual occasions, the results are not always significant, and sometimes the difference in mean values is even in the opposite direction (Table 12). Therefore, interpretation of the overall results must be cautious. Further reasons for caution include the small sample sizes on individual dates, the fact that the data usually came from repeated observations of an even smaller number of individual whales, and the lack of proper control observations in most instances. The great variability in bowhead behavior on all time scales--surfacing to surfacing, day to day, year to year--makes it especially difficult to compare observations in the presence of seismic noise at one place and time with observations in the absence of seismic noise at another place and/or time.

Our overall results suggest that quantitative changes in surfacing, respiration and dive cycles sometimes occur as a result of seismic noise, but corroboration is needed. It would be especially valuable if further controlled experiments could be done. The same whales should be observed before, during and after periods of noise from a full-scale seismic source.

Assuming that the effect is real, why did we find rather consistent evidence of altered behavior in the presence of seismic noise in 1982 but not in 1980-81 (Table 12)? The 1982 observations all involved noise from an airgun array, whereas the 1980-81 observations involved sleeve exploders, an airgun array, and a single airgun. However, all of these source types produced pulsed sounds with generally similar durations and inter-pulse intervals. At long horizontal ranges, the frequency composition of pulses from the various sources was also generally similar, although this may not be true within a few kilometres from the sources (Greene 1982, 1983).

The received levels of the seismic sounds did not seem to relate in any consistent way to the apparent occurrence of altered behavior. No major effects were detected in two of three cases with received level >140 dB//1 µPa; most cases of apparent effects were found with lower received levels (Table 12).

The deeper water at most locations where bowheads were observed in 1982 than at most observation sites in 1980-81 was presumably responsible for our detection of seismic signals at greater ranges in 1982 than before. It is also possible, although unproven, that whales typically were diving to deeper depths in 1982. The much longer average duration of dives in 1982 than in 1980-81 (Würsig et al. 1983) may be indicative of greater average depth of dives in 1982. If the whales were diving deeper in 1982, they may have been encountering stronger received levels of seismic impulses than at corresponding ranges in 1980-81. However, it is doubtful that the year-to-year difference attributable to greater dive depths would be significant. The reduction in received level occurs only within a few metres of the surface for sounds at frequencies 100-300 Hz. Even in 1980-81, most dives were presumably to depths greater than a few metres.

If seismic noise is unpleasant to bowhead whales, one could hypothesize that dive durations would be shorter in the presence of seismic noise. By terminating a dive and returning to the surface, a whale could reduce the received level of the seismic pulses. It might also reduce the received level by not diving as deeply, which in turn might reduce the average duration of dives. Our data do suggest that dive duration tends to be reduced in the presence of seismic noise, but the effect seems to be small and quite inconsistent (Tables 12 and 13, Figs. 7 and 8).

Since bowheads normally dive to feed, and presumably there is a strong inclination to feed while in the Beaufort Sea in summer, one might expect that unusually brief dives resulting from disturbance by seismic noise might also be followed by unusually brief surfacings. Even in the absence of disturbance, the number of respirations per surfacing is closely correlated with the length of surfacing (Würsig et al. 1983). Hence, a reduction in number of blows per surfacing would also be expected. Decreased surface times with unusually few blows were indeed evident in the presence of seismic noise (e.g., Table 12). Furthermore, in mid August 1982 we found that surface-dive cycles as a whole tended to be shorter with seismic noise than without it (Table 15). Thus, the observations are consistent with the idea that bowheads sometimes alter their surface-dive cycles in a way that minimizes the duration of continuous exposure to intense seismic pulses.

Based on the 1980-81 data, we suggested that whales may react more strongly to the onset of seismic noise than they do to ongoing seismic exploration (Fraker et al. 1982). We suggested this because we found no clear reactions to ongoing seismic, but had found indications of response to a single airgun fired near the whales for only 20 min. The data now available do not support this distinction. There now is evidence of reactions to ongoing seismic exploration on some occasions. Furthermore, reanalysis of data from the airgun experiments indicates that the reactions to the first airgun test were not as clear cut as initially believed (see above).

In summary, bowhead whales normally do not swim away from seismic vessels that are operating as close as several kilometres away. They appear to continue with normal kinds of activities, including underwater calling. However, quantitative analysis of data concerning surfacing, respiration and diving indicates that surface-dive cycles sometimes tend to be shorter in duration in the presence of seismic noise. Although overall analyses indicate that the effect is statistically significant, the response is quite variable. Further observations, preferably from controlled experiments, are needed to confirm its generality of occurrence. The significance of the apparent change in behavior to the well-being of the whales cannot be evaluated with existing data. However, alterations of surfacing and diving cycles could affect feeding success and social interactions, at least on a short-term basis.

REACTIONS OF BOWHEADS TO DRILLING

Drilling noise is more or less continuous, unlike noise from boats, aircraft and seismic exploration. In 1980-81 we obtained only limited information about the behavior of bowheads in the presence of this noise (Fraker et al. 1982). On several occasions Fraker et al. saw bowheads within 20 km of drillships. The closest sighting was of three whales only 4 km from an operating drillship, and industry personnel reported bowheads within 1 km of drillships. The literature contains very little additional information about the reactions of any marine mammals to drilling (for review, see Richardson et al. 1983b).

Initial drilling in the Alaskan Beaufort Sea has been from artificial and natural islands in shallow nearshore waters. When drilling extends to somewhat deeper water, it is expected to be done from bottom-supported cones or caissons. Caissons are already in use as drilling platforms in the Canadian Beaufort Sea. In the latter area, conventional drillships are used for drilling in deeper water, but it is not expected that drillships will be used in the Alaskan Beaufort Sea in the near future.

Studies of the responses of bowheads to drilling on artificial islands are especially desirable, since this is the most imminent type of drilling in the Alaskan Beaufort Sea. However, drilling from 'conventional' artificial islands has not been underway in the eastern Beaufort Sea during any of our field seasons. Hence, it has not been possible to obtain either observations of bowhead behavior or recordings of underwater noise near such operations. To our knowledge, no recordings of noise from drilling on an artificial island surrounded by open water exist. This has prevented us from performing playback experiments with such sounds. Instead, we used our recordings of drillship sounds during playback experiments in 1982.

Drilling from 'Tarsiut', a caisson-retained island, did continue for the first few days of our 1982 field season. We searched for bowheads near this island and attempted to obtain recordings of underwater sounds nearby.

Methods

Observations near Tarsiut Island

Tarsiut is a drilling platform consisting of dredged material contained within four connected concrete caissons. The caissons rest on a subsea berm, also composed of dredged material. Tarsiut is located at 69°54'N, 136°20'W in 23 m of water. Tarsiut was completed late in 1981, and two wells were drilled between then and early August 1982. During the remainder of August 1982, the second well was tested. Throughout August there was much activity around Tarsiut; usually there were about 6 supply boats, barges and other vessels within 2 or 3 km.

Intermittently throughout August, we used the Islander observation aircraft to search for bowheads near Tarsiut. The search effort and bowhead sightings by 5-d periods are mapped in the accompanying 'Distribution in relation to industrial activity' section (Richardson et al. 1983a). Industry personnel on the island were asked to report any bowhead sightings promptly via radio. The 'Sequel' travelled to Tarsiut during its first cruise within the 1982 field period in the hope of recording drilling sound. However, drilling had ceased before 'Sequel' arrived; waterborne sounds from well testing and other activities were recorded at various ranges from the island (Greene 1983).

Observations near Drillships

Routes of the observation aircraft were also chosen to pass, whenever practical, near one or more of the four drillships operating in the eastern Beaufort Sea (Richardson et al. 1983a). We found bowheads within 20 km of drillships during three flights in 1982, on 11 August and the morning and evening of 31 August (Table 17). On each occasion a sonobuoy was deployed near the whale(s) to record any drillship or bowhead sounds. On 11 August wave heights were too great to permit useful behavioral observations, but during the two flights on 31 August we circled for prolonged periods to observe behavior. For completeness, we also re-examined behavioral data from our previously reported observations (Fraker et al. 1982) of bowheads 15-20 km and 4 km from a drillship on 23 August 1981. The new criteria for acceptance of data adopted in 1982 were applied during this reanalysis of 1981 data.

Industry personnel aboard drillships and helicopters servicing the drillships were requested to report bowhead sightings promptly.

Drillship Noise Playback Experiments

We conducted drillship noise playback experiments near bowhead whales on three occasions in mid August 1982 (Table 18). The basic approach and some of the complications were described in the General Methods section. All experiments were in water 125-150 m deep east or northeast of Herschel Island off the Yukon coast. Drillship sound was projected into the water from the 'Sequel' while behavioral observations were obtained from the observation aircraft circling at 457 m a.s.l. overhead.

Table 17. Circumstances of observations of bowheads near drillships, 1981-82.

	23 Aug '81	23 Aug '81	11 Aug '82	31 Aug '82	31 Aug '82
Location - N. Lat. W. Long.	70°04' 134°54'	70°05' 134°28'	70°50' 134°18'	70°28' 136°51'	70°27' 136°30'
Water Depth (m)	30	23	90	550	150-390
Sea State	2	2	3-4	1-2[a]	2
Aircraft Altitude (m)	457-610	610	457	457[b]	457
Duration of Observation (min)	62	63[c]	26	113[b]	194
Drillship					
Identity	Expl. II	Expl. II	Expl. IV	Expl. III	Expl. III
Range (km)	15-20	4	17	18-19	10-12
Activity	Drilling	Drilling	Not drilling	Drilling	Drilling
# of whales	8+	3	1+	1	2
Activity of Whales	Some echelon feeding & socializing; calling	Mainly socializing; no calls detected	Unknown; some calling	Slow to medium speed travel; calling	Long dives; slow to medium travel; some callin

[a] No whitecaps but heavy swell.
[b] Subsequent observations from 305 m a.s.l. are not considered here.
[c] Excludes subsequent observations when boats nearby.

Table 18. Circumstances of the three drillship noise playback experiments near Herschel Island, 16-19 August 1982.

	16 Aug '82	18 Aug '82	19 Aug '82
Location - N. Lat.	69°43'	69°36'	69°41'
- W. Long.	138°13'	138°22'	138°32'
Water Depth (m)	150	125	150
Sea State	1	1-2	1
Aircraft Altitude (m)	457	457	457
Durations (min) of			
Post-Boat	30	-	20
Quiet Boat	52	159[a]	93[a]
Playback, incr. level	13	10	9[b]
Playback, peak level	10	10	-
Playback, decr. level	10	10	-
Post-playback	-	10	34
Source Level of Sound during Peak Period (dB//1 µPa @ 1 m)	155	164	157
Approx. distances (km),			
Projector to Sonobuoy	2	2	1.5
Projector to Whales	2-4.5	3-6.5	2-4.5
Noise level at Sonobuoy (dB//1 µPa)			
Ambient[c]	85	101	92
Seismic Pulses	-	<125-133	-
Playback, peak[d]	100/94	110/105	99/92
Activity of Whales	Slow travel; some faster travel during playback	Slow to rapid travel; some aerial activity and socializing	Slow travel, nursing; calf moves along windrow of debris

[a] Playback delayed because calf present.
[b] Playback terminated early because calf present.
[c] 10-1000 Hz band, immediately before and after playback.
[d] The levels for the 10-1000 Hz band and for the 275 Hz tone are given.

The sequence of activities leading up to a playback was as follows. The 'Sequel' maneuvered slowly to a point within 1 km from a group of bowheads and the motor was stopped. The observation aircraft arrived overhead either before the 'Sequel' approached the whales (16 August), about 10 min after 'Sequel's' motor was stopped (19 August), or several hours after 'Sequel' stopped (18 August). A sonobuoy was dropped near the whales soon after the aircraft arrived. Control observations did not begin until at least 30 min after the 'Sequel' had stopped. We intended the control phase to last about 45-60 min, but in two cases it was prolonged because bowhead calves were in the area. When we believed that no calves were within about 3 km from the 'Sequel', the playback period began.

The sounds broadcast underwater were sounds of the drillship 'Explorer II' recorded in 1981 at the North Issungnak drillsite. Most of the drillship noise was at frequencies between 50 and 750 Hz, with a strong tone at about 275 Hz (for spectrum, see Greene 1982, p. 322). The sounds were broadcast by a standard U.S. Navy J11 underwater projector suspended at a depth of 9 m. The power source was a 250 W Bogen MT250 amplifier powered by 12 V batteries. The sounds were broadcast for about 30 min. During the first 10-13 min, the sound level was gradually increased from zero to peak intensity. After a 10-min period at peak intensity, the level was gradually reduced to zero over 10 min. This approach was used to avoid a sudden onset of sound at peak intensity and the startle response that this might evoke. We suspected that the gradual change in level might more closely simulate what a bowhead would encounter as it approached a drillsite.

The output of the J11 projector was monitored by a hydrophone rigidly mounted 1.9 m in front of the projector. The sound received by this hydrophone was monitored in real time via loudspeaker, oscilloscope and voltmeter to ensure that it was undistorted, and to determine its source level. The drillship sound received by the sonobuoy was also recorded and analyzed (e.g., Greene 1983, Fig. 23).

Because of limited aircraft endurance or approach of fog, the aerial observers were unable to observe for long (if at all) after the playbacks ended (Table 18).

Playback experiments were completed on two occasions (16 and 18 August). A third experiment was aborted 9 min into the increasing-level phase when a bowhead calf appeared about 2 km from the 'Sequel' (19 August). On a fourth occasion (later on 19 August), the 'Sequel' and observation aircraft were in place and control observations were obtained, but presence of calves, gradual dispersal of the whales, and approach of fog precluded a playback. No other opportunities for playback experiments were available.

Results

Observations near Tarsiut Island

Many of our flights during the 1-31 August 1982 period came within 10 or 15 km of Tarsiut. However, our closest bowhead sighting was 21 km north of Tarsiut (and 28 km from the 'Explorer I' drillship) on 4 August.

Industry personnel on Tarsiut reported no bowhead sightings during our field season in August 1982, but did see bowheads on at least three other occasions in 1982. On 25 June, one bowhead was reported only 200 m away amongst white whales. On 26 June three bowheads were seen with white whales at an unspecified distance; drilling was in progress. On 19 September two bowheads were reported about 300 m from the island.

Observations near Drillships

We saw bowheads within 20 km of drillships on three occasions in 1982.

11 August 1982. -- At least one bowhead was seen 17 km from the 'Explorer IV' drillship, but the sea was too rough for behavioral observations (Table 17). The rig on the drillship was working in the Kenalooak J-94 drillhole, but was not actively drilling. A sonobuoy dropped near the whale(s) showed that the human ear could sometimes detect low frequency industrial noise above the sea noise. The total noise power, ambient plus industrial, was 103 dB//1 μPa in the 10-1000 Hz band. There were tones at several frequencies between 14 and 195 Hz. The strongest tone was 93 dB//1 μPa at 169 Hz (C.R. Greene, pers. comm.). Several faint whale calls were detected in 1.5 h of recording (see Table 9 in Würsig et al. 1983).

31 August 1982 (Morning). -- One bowhead was observed for 3.5 h at a location 18-19 km northwest of the 'Explorer III' drillship (Table 17). During the last 1.7 h of this period the aircraft descended to 305 m a.s.l. to conduct an aircraft disturbance experiment. Only the initial 1.9 h period when the aircraft was at altitude 457 m is considered here. The drillship had just returned to the Orvilruk 0-03 drillsite, and was drilling out the plugs that had been installed when drilling was suspended in 1981. A supply ship steamed slowly back and forth near the drillship and 15-19 km from the whale throughout the period of observation. No tones were evident in the noise spectrum received by a sonobuoy near the whale. There was a broad peak at 50-70 Hz; its spectrum level was 80 dB//1 $\mu Pa^2/Hz$. The broadband noise level was 101 dB//1 μPa in the 10-1000 Hz band, which is not much higher than typical ambient levels in the absence of industrial sources.

The whale travelled in various directions at slow or medium speed during most of the observation period. It remained 18-19 km from the drillship throughout the entire period of observation. There was no indication that its behavior was affected by the drillship or otherwise unusual. Its dives and blow intervals averaged 12.8 min and 13.5 s in duration, respectively. These values are very similar to the overall 1982 averages of 12.1 min and 14.9 s, respectively (Table 19). Sample sizes for other variables were too small for meaningful comparisons. Many bowhead sounds, mostly low frequency tonal calls, were detected by the sonobuoy. However, few calls were loud (see Table 9 in Würsig et al. 1983).

31 August 1982 (Evening). -- Two bowheads were observed, one at a time, for 3.2 h at locations 10-12 km north and later northwest of the 'Explorer III', which was drilling at Orvilruk (Table 17). Again, no tones were evident in the noise received near the whales, and there was a broad peak at 50-70 Hz and 80 dB//1 $\mu Pa^2/Hz$ (Greene 1983, Fig. 3). The broadband level was 100-101 dB in the 10-1000 Hz band.

The whales were travelling SW-W at slow to medium speed during both their surfacings and their dives. Their distance from the drillship remained similar throughout the observation session, since they were moving slowly WSW from an initial location north of the ship. All of the dives were very long, but otherwise the behavior of the whales was not unusual. The five dives whose durations were recorded averaged 27.6 ± s.d. 2.74 min in length. The dive durations were very consistent, ranging from 23.4 to 31.0 min. Blow intervals averaged 15.72 ± 3.759 s (n = 58). This value was longer than that recorded for a different whale several kilometres away earlier in the day (13.50 ± 5.711 s). However, it was similar to the mean for all 'presumably undisturbed' non-calf bowheads observed in 1982 (14.86 s; Table 19). Relatively few bowhead sounds were recorded by the sonobuoy dropped near the whales (see Table 9 in Würsig et al. 1983). All of these sounds were low frequency tonal calls of the usual types. Given the low received intensities

able 19. Surfacing, respiration and dive characteristics of non-calf bowheads observed in the resence and absence of drillships, 1981-82.

Date(s)	Nearest Drillship	Mean	s.d.	n	Mean	s.d.	n
		# Blows/Surfacing			Duration of Surfacing (min)		
3 Aug 81	Explorer II, 15 km	3.76	4.40	17	0.84	0.934	19
3 Aug 81	Explorer II, 4 km	8.44	3.00	9	1.64	0.519	9
3 + 24 Aug 81	-	4.90	3.09	31	1.43	0.872	37
1 Aug 82	Explorer III, 19 km	7.50	2.12	2	1.50	0.071	2
1 Aug 82	Explorer III, 11 km	-	-	0	-	-	0
ll 1982	-	7.43	5.11	58	2.05	1.320	70
		Blow Interval (s)			Dive Duration (min)		
3 Aug 81	Explorer II, 15 km	12.40	5.665	65	0.49	0.579	11
3 Aug 81	Explorer II, 4 km	11.98	4.385	62	11.26	4.821	5
3 + 24 Aug 81	-	13.67	6.190	190	8.18	8.202	13
1 Aug 82	Explorer III, 19 km	13.50	5.711	34	12.79	2.150	5
1 Aug 82	Explorer III, 11 km	15.72	3.759	58	27.57	2.738	5
ll 1982	-	14.86	8.660	794	12.08	9.153	51

of these calls, they may not have been produced by the whales being observed near the sonobuoys.

Aside from the unusually long dive durations, the behavior of the two whales was similar to that of many other bowheads seen in 1982. Accordingly, these observations were classified as 'presumably undisturbed' and were included in the analyses of normal behavior presented by Würsig et al. (1983).

23 August 1981. -- Observations of bowheads 15-20 km and also 4 km from the 'Explorer II' on this date were described by Fraker et al. (1982). In both areas, the whales were socializing, with some echelon feeding at the more distant location (Table 17). Fraker et al. found that behavior of the three whales 4 km from the ship was somewhat unusual, relative to behavior 15-20 km from the ship and relative to that of all 'presumably undisturbed' bowheads in similar water depths. Durations of surfacings and dives were rather long, and number of blows per surfacing was correspondingly high. However, the whales were not moving away from the ship.

The same results were obtained upon re-examination of the 23 August 1981 data with the new criteria adopted in 1982 (Table 19). However, it is noteworthy that mean values for all variables were within the ranges encountered in 1982. Whether the somewhat unusual behavior found 4 km from 'Explorer II' had any connection with the presence of the ship remains unknown.

A sonobuoy dropped near the whales 4 km from the drillship showed that industrial noise was clearly evident. Greene (1982) found that the dominant sound from 'Explorer II' while it was drilling at this location was a tone at about 278 Hz; its level 4 km from the ship was about 111 dB//1 μPa. Many bowhead calls were detected by a sonobuoy near the whales 15-20 km from the drillship. No calls were detected by the sonobuoy near the whales 4 km from the drillship (Würsig et al. 1982, p. 113).

In summary, on several occasions in 1981 and 1982 we have seen bowheads in areas ensonified by drillship noise. The bowheads were not moving away from the ship on any of these occasions. Behavior sometimes has been indistinguishable from 'normal'. However, on two occasions dive durations have been unusually long, and on one the durations of surfacing and number of blows per surfacing were also rather long. Some groups of bowheads called in the presence of drillship noise. However, the apparent lack of calling by the socializing group seen 4 km from a drillship on 23 August 1981 is noteworthy, since socializing whales normally call frequently (Würsig et al. 1982).

Industry Sightings. --In 1982, we received only two reports of bowheads seen from or near drillships. On both 25 July and 15 August, a single bowhead was seen an estimated 2 n. mi. (3.7 km) from 'Explorer II', which was at the Irkaluk drill site. Fraker et al. (1982) reported several sightings from drillships in 1980, including seven at estimated distances of 0.2-5 km. Whales were reported to be 1 km or less from 'Explorer IV' on both 3 and 4 August 1980, and at ranges 1.4-5 km on 2 and 5 August 1980. Whales were reportedly visible from the ship through most of the day on 4 August.

Drillship Noise Playback Experiments

Playback experiments were completed on 16 and 18 August 1982, and a third partial experiment was done on 19 August. Table 18 summarizes the circumstances of each experiment. Only a few whales were under observation during each of these experiments. Given the long dives encountered in 1982, the number of surfacing and dive sequences recorded in each single experiment was too small for separate analysis. Hence, we have pooled the results of the three experiments before analysis. A two-way analysis with 'phase of experiment' and 'date' as factors would be preferable, but this was precluded by small sample sizes and some empty cells.

Sound Levels to Which Bowheads were Exposed. -- The whales whose behavior was observed in detail during the playback phases of the experiments were estimated to be 2-6.5 km from the underwater sound projector. The peak sound levels received at sonobuoys 2, 2 and 1.5 km from the projector during the three experiments were 100, 110 and 99 dB//1 μPa, respectively (broadband level, 10-1000 Hz band). Corresponding ambient levels before and after the playback periods were 85, 101 and 92 dB (Table 18). Thus, the playbacks increased the sound levels 1.5 or 2 km from the projector by 15, 9 and 7 dB, respectively. The whales closest to the projector were at about the same range as the sonobuoy during each experiment. The most distant whales observed during the experiments were 2-3 times as far from the projector than were the sonobuoys, so received levels there would be several dB lower. (Assuming spherical spreading, received sound level decreases 6 dB when the range is doubled.)

The hearing abilities of bowheads are unknown, but dolphins apparently can detect a <2 dB change in intensity (Bullock et al. 1968; Johnson 1971). If bowheads have similar sensitivity, most of the whales under observation, with the possible exceptions of the most distant ones in the 18 and 19 August experiments, should have been able to detect the intensity change. The difference in spectral characteristics of ambient and drillship sound would provide additional cues for detection of the playbacks.

Although most or all whales observed during the playbacks probably could detect the drillship noise, the drillship noise levels received by the whales were not very high. The strongest tone in the drillship noise was at about 275 Hz. Its received levels at the sonobuoys were 94, 105 and 92 dB in the three experiments. These levels are equivalent to those that would be received 12, 6.5 and 13 km from the drillship itself, based on Greene's (1982) equation for received level vs. range. The closest whales were at about the same ranges as the sonobuoys, and thus were exposed to sounds roughly equivalent to those 12, 6.5 and 13 km from a drillship.

Behavior of the Whales. -- Blow intervals before, during and after playback periods did not differ significantly (Table 20; $F = 1.35$, $df = 2, 307$, $p > 0.1$). The mean value during playbacks was less than the means before and after playbacks, but not significantly so ($t = 1.49$ and 1.28, respectively). We do not know if other surfacing, respiration and dive variables were affected because they were rarely recordable during the brief playback periods.

To test the hypothesis that whales would move away from the source of drilling noise, orientations of whales relative to 'Sequel', from which the noise was broadcast, were examined for the before and during playback

Table 20. Surfacing, respiration and dive characteristics of non-calf bowheads observed before, during and after the playbacks of drillship noise, 16-19 August 1982.

Phase of Experiment	Mean	s.d.	n	Mean	s.d.	n
	# Blows/Surfacing			**Duration of Surfacing (min)**		
Control	8.14	4.824	22	1.98	0.822	27
Playback	2	-	1	1.77	1.131	2
Post-playback	-	-	0	-	-	0
	Blow Interval (s)			**Dive Duration (min)**		
Control	14.12	6.019	245	9.09	7.711	12
Playback	12.85	4.966	58	10.00	-	1
Post-playback	15.29	2.215	7	-	-	0

periods. Only the first observation of each 'non-calf' whale in each period was used. Headings of the whales were converted into deviations from the 'directly away from Sequel' direction, i.e. 0° = directly away, 180° = directly toward. When applied to these deviation scores, the V-test (Batschelet 1972) showed no evidence that the whales were orienting away from 'Sequel' in the before playback periods ($V = 2.67$, $n = 26$, $p>0.1$). However, there was evidence of orientation away during playbacks ($V = 4.87$, $n = 15$, $0.05>p>0.01$). None of the 12 whales within 4.5 km of 'Sequel' during the playback periods was approaching 'Sequel'; 10 moved away and two moved tangentially.

There were indications that the whales tended to move faster during the playback periods, as well as more consistently away from 'Sequel'. During the pre-playback control periods, motion was recorded as nil or slow for 12 surfacings and moderate or fast for eight. During playbacks, the corresponding figures were 1 and 7 ($chi^2 = 5.18$, $df = 1$, $p<0.025$). The increase in speed, coupled with more consistent orientation away from 'Sequel' during the playback phase, was sufficiently distinctive that it was noticed in real time by the observers in the aircraft. However, the reactions were not nearly as conspicuous as those during close approach by a boat.

Turns occurred at similar frequency within surfacings in the control and playback periods. The whales turned during 7 of 34 control surfacings and during 3 of 13 surfacings during playbacks.

In all three playback experiments, the apparent rate of calling was much reduced from that before the playback period (Table 21). However, some bowhead calls of the usual types, mostly faint calls from distant whales, were recorded via the sonobuoys during the playback phases. Although whales tended to move away from the 'Sequel' as each experiment progressed, the reduction in call rate does not seem to have been an artefact: after the end of each experiment, the total call rate returned to a level near that before the playback period, and the rate of loud calls also increased (Table 21). The elevated noise level during playbacks may have masked some faint calls, artefactually reducing the apparent total call rate, but it did not mask the louder calls. Thus, the reduced call rate during playbacks was probably real.

In summary, bowheads appeared to move more consistently and rapidly away from the playback site during the playback periods than they had before the playbacks began. However, the reaction was not as dramatic as that to close approach by a boat. The rate of calling also decreased during playbacks. Sound levels received by the closest of the whales were similar to those several kilometres from an actual drillship.

Gray Whale. -- About 3 min into the 'increasing level' phase of the playback experiment on 18 August, a gray whale (Eschrichtius robustus) surfaced about 5.5 km from 'Sequel'. Initially this whale moved rapidly eastward, toward 'Sequel'. It is doubtful that the drillship sound was detectable at this distance, since it was not yet being projected at high intensity. About 6 min into the playback, the gray whale dove. It resurfaced about 4.5 km from 'Sequel' 1 min after the peak level was reached. It was then oriented tangentially, and moved slowly until it dove again 4 min into the peak playback period. The last confirmed sighting of this gray whale was 7 min into the decreasing level phase. It was then 3 or 4 km from 'Sequel' and moving slowly westward (away). Whether the reorientation was attributable to the drillship noise is unknown.

Table 21. Call rates of bowheads during three drilling noise playback experiments, 1982[a].

	Quiet Boat	Playback Level: Increasing	Peak	Decreasing	After Playback
Loud Calls/Whale-h					
16 Aug '82	8.3	6.9	0.0	4.0	1.1
18 Aug '82[b]	2.6	0.0	0.0	0.0	1.8
19 Aug '82	3.8	0.0	–[c]	–	3.8
Total Calls/Whale-h					
16 Aug '82	49.2	31.5	4.0	17.0	35.0
18 Aug '82[b]	29.9	23.9	2.3	22.5	35.0
19 Aug '82	29.4	21.5	–[c]	–	17.1
Whale-h					
16 Aug '82	5.2	1.3	1.0	1.0	1.8
18 Aug '82[b]	10.9	1.5	1.3	1.3	4.0
19 Aug '82	12.9	1.4	–[c]	–	4.2

[a] Data compiled by C.W. Clark.
[b] Seismic signals were present throughout the experiment on 18 August 1982.
[c] The playback on 19 August 1982 was terminated before the peak level phase because a bowhead calf was detected.

This was our only sighting of a gray whale in the eastern Beaufort Sea in 1982. Three were seen there in 1980 (Rugh and Fraker 1981) and one was seen in 1981 (Würsig et al. 1983).

Discussion

Our observations show that bowheads sometimes approach to within a few kilometres of operating drillships and remain there for at least several hours. Their behavior in these cases is not conspicuously different from normal, although it is possible that quantitative differences in surfacing and dive cycles may sometimes occur. Drillship noise is clearly detectable in the water at ranges of several kilometres. Industry personnel have reported bowheads even closer to drillships than we have observed.

The playback experiments in 1982 suggested that some bowheads may react to the presence of drillship noise in the water at intensities similar to those found several kilometres from a real drillship. The reactions were not nearly as clear cut as those to an approaching boat, but there was limited evidence of (1) orientation away from the sound source, (2) faster motion than before the sound was turned on, and (3) decrease in the rate of calling.

Why did the behavior of bowheads seem to be affected more strongly by drillship noise playbacks than by drillships themselves? As described above, the sound levels reaching the whales during the playback experiments were similar to or less than those reaching whales that we have observed near drillships. One of the usual possibilities--that controlled experiments are better able to detect subtle effects--does not seem to be the explanation in this case. Bowheads clearly remained near drillships for hours at a time, whereas some bowheads apparently oriented away from the playback sites within minutes.

One obvious difference between the two situations is that the playbacks lasted only 30-33 min, whereas a drillship produces sounds continuously (although with occasional changes in sound characteristics--Greene 1982). Animals frequently react more strongly to a stimulus when it is first presented than they do after a prolonged period. It is interesting that some whales apparently reacted to the playbacks despite the fact that we increased and decreased the playback intensity gradually over 10-13 min in an attempt to avoid 'startle' responses. Perhaps even a 10-min period of gradually increasing level is perceived differently than the slower increase in level that a whale would experience as it swam toward a drillship.

Our few playback experiments must be considered preliminary. Although the logistics of playback experiments far offshore are difficult, future experiments should involve more trials, longer trials, reduced distance from whales, and blind observation protocols. Also, non-industrial sounds should be broadcast near bowheads to test whether they react specifically to drilling noise, or more generally to any novel sound. Clark and Clark (1980) found that right whales tended to move away during playbacks of recorded water noise, a 200 Hz tone, or humpback whale sounds; Cummings and Thompson

(1971) found that some gray whales presented with random noise or pure tones turned away temporarily.

Our observations show some degree of tolerance of drillship operations. However, the playback experiments suggest that avoidance can occur in at least the short term. How relevant are these observations to the question of drilling in the Alaskan Beaufort Sea? Islands and other bottom-mounted structures are the current and anticipated platforms for drilling there. Reactions of bowheads to drillships and to drilling from islands may differ. Sound propagation from these structures into the sea probably is quite different. Malme and Mlawski (1979) detected low frequency tones from drilling on an icebound island to ranges of 7-11 km under low ambient noise conditions, and to only about 2 km under high noise conditions. These ranges appear to be less than those to which drillship noise propagates. However, the applicability of the Malme and Mlawski winter measurements in shallow ice-covered water to the summer and fall situation in somewhat deeper water is also questionable. It is desirable that sounds from drilling on islands be better characterized, and that the reactions of bowheads to such sounds be studied.

CONCLUDING REMARKS

Progress in 1982

The purpose of this study was to determine, by experimental and observational means, the immediate behavioral reactions of bowhead whales to potential sources of disturbance. We have found strong reactions to approaching boats and aircraft, and subtler, variable reactions to drilling and seismic noise. Overall, however, we found considerable tolerance of ongoing seismic, dredging and drilling operations. In 1982, we obtained new information about reactions to most of these sources of potential disturbance. The most noteworthy new information concerned seismic and drilling noise.

Previous to 1982, the available information suggested that bowheads may react to the start-up of seismic (geophysical) exploration, but show no overt response to ongoing seismic operations as close as 6-13 km away (Fraker et al. 1982). In 1982 we found, for the first time, indications that bowhead behavior sometimes is altered subtly by noise from distant geophysical exploration. However, we again found no evidence of avoidance.

Information available before 1982 also provided no clear evidence that bowheads react to or avoid drillships. The 1982 work corroborated that some bowheads approach to within 10 km from drillships. However, drillship noise playback experiments suggested that some bowheads will move away from the source of drilling noise, at least in the first half hour after it begins. This experimental evidence is consistent with a trend noted in our 1980-81 report: bowheads tend to react more strongly to the introduction of a type of disturbance not present in preceding hours (boat, aircraft, airgun or drillship playback) than they do to ongoing industrial operations.

The 1982 work also has provided corroborative evidence regarding reactions of bowheads to aircraft and boats. The new information is consistent with earlier indications that reactions to our observation aircraft were frequent when it was $\leq$305 m (1000 ft) a.s.l., infrequent when it was at 457 m, and not detected when it was at $\geq$610 m. The one boat disturbance experiment in 1982 provided confirmation that bowheads react strongly to an approaching boat even when already exposed to seismic noise. The new results are also consistent with the suggestion that bowheads may be especially sensitive to boats when other types of industrial noise are detectable in the water near the whales.

Data Gaps

A number of important questions about reactions of bowheads to aircraft and vessel traffic remain unanswered. Neither we nor other workers have obtained any systematic information about reactions of bowheads to helicopters. Because many helicopters produce rather intense sound with many tonals (Greene 1982), reactions of bowheads may be more pronounced than those to fixed wing aircraft. Bowheads react strongly but rather briefly to one pass by a boat; however, there is no information about effects of repeated boat traffic. Reactions of bowheads and other baleen whales to hovercraft are unknown.

The effects of seismic exploration on bowheads are not well understood. The pulses of noise from seismic vessels are by far the most intense type of noise introduced into the sea by normal industrial operations. Several areas of uncertainty can be identified:

- The long-distance horizontal propagation of such noise in shallow waters has not been studied in much detail. Greene (1982, 1983) obtained some data on propagation during this study, but one cannot extrapolate the results to different areas, such as the Alaskan Beaufort Sea, where propagation conditions probably are different.

- Factors responsible for the seemingly variable responses of the whales to seismic noise are not understood. Sometimes we have found no detectable behavioral response at ranges as close as 6-13 km, and on other occasions we have found apparent responses at much greater ranges and lower received noise levels. Is this difference an artefact of differences in our ability to detect effects, or does the sensitivity of the whales to seismic noise vary greatly?

- Assuming that bowheads do react to distant seismic exploration on some occasions, what is the biological significance of these reactions? The apparent reactions detected in 1982 were quite subtle. It is uncertain how disruptive or deleterious such inconspicuous changes in behavior might be.

- Is there any range at which bowheads will actively avoid seismic noise? Neither we nor Ljungblad's team have detected active avoidance, and industry personnel report seeing bowheads even closer to seismic vessels than we have noticed.

- Can bowheads in shallow waters detect the direction of arrival of a very intense, low-frequency sound such as a seismic pulse? If not, this could explain their failure to move away from seismic ships.

- Whether or not bowheads ever actively avoid seismic vessels in the short term, does exposure to seismic noise in a particular area affect the likelihood that bowheads will return to that area in the future? (Existing information on this point is discussed in Richardson et al. 1983a.)

- How does seismic noise affect the hearing system of bowheads? Seismic noise can be 100 dB or more above ambient levels out to several kilometres from the seismic vessel. Are such intense sounds 'unpleasant' or harmful to the hearing system of bowheads?

To answer all of these questions would require a study broader in scope than this. However, with sufficient control and replication, an experimental study of short-term behavioral responses could address some of these questions. It could examine the factors affecting the occurrence and severity of overt reactions, and could determine how close a seismic vessel could come before the whales began to swim away.

The most important question about the reactions of bowheads to drilling concerns the potential differences between drilling from ships, islands and other platforms. Noise propagating into the water from these platforms is expected to differ considerably. However, no measurements of underwater noise from drilling on an artificial island surrounded by open water have been published, insofar as we know. Also, it would be desirable to corroborate the limited 1982 evidence that bowheads react to the onset of drilling noise at levels similar to those several kilometres from a drillship. Bowheads show considerable tolerance of ongoing drillship operations.

Only limited information about reactions of bowheads to dredging has been collected. Bowheads sometimes approach to within several kilometres of an active dredge (Fraker et al. 1982), but there have been no detailed observations of their behavior near a dredge. No experimental work with dredge noise has been done.

Implications of Short-term Behavioral Reactions

This study was designed to detect and characterize any overt behavioral responses of bowheads to various industrial activities. Strong responses to boats and aircraft have been found in some situations, and weaker responses to seismic and drilling noise have also been detected. The strong flight responses to boats cease as the boats move away, although the whales may remain scattered for some time thereafter. Conspicuous reactions to aircraft occur during overflights at low altitude, but do not seem to persist for long if a circling observation plane subsequently avoids flying directly over the whale. Most of the other responses that we have detected have been less conspicuous. In the presence of seismic noise or drillships, there sometimes is evidence of adjustments in the mean durations of surfacings and dives, the number of respirations per surfacing, the intervals between blows, or the rate of calling. However, the adjustments are usually slight and their causal connection with the seismic or drillship noise is difficult to confirm. The whales generally do not seem to move away from seismic vessels, drillships or dredges.

What is the significance to the whales of the brief and/or subtle changes in behavior that we have detected? An occasional brief interruption of feeding by a passing boat or aircraft is unlikely to be very significant provided that the whales do not vacate the feeding area and that they resume feeding soon after the boat or aircraft leaves.

Disruption of close social groupings might have more prolonged effects. We have noticed increased spacing between whales after some boat disturbance incidents, and there was an indication of reduced echelon size among skim-feeding whales during one airgun experiment (Fraker et al. 1982). Our data on the durations of the periods of increased spacing are not very extensive. Disruption of mating groups or mother-calf pairs could be particularly serious. Female bowheads sometimes become separated from their unweaned calves by distances up to 1 km (Würsig et al. 1982, 1983). If a boat approached during one of these temporary separations and caused the whales to flee, the mother and calf might be especially likely to become separated permanently.

The subtle alterations in behavior that we sometimes detected or suspected may also be significant as indicators of unobservable internal effects. Stress effects are difficult to study in any animal, and would be especially so in large whales. Nonetheless, stress might occur as a result of noise or other stimuli from industrial activity, and seemingly minor changes in overt behavior might be the one observable manifestation. One way to establish a connection between overt behavior and stress might be to conduct disturbance experiments in which radio-telemetry is used to monitor physiological and behavioral parameters at the same time as behavior is observed.

The potential effects of industrial noise on communication between bowheads is still a subject of concern. We and other workers have found that bowheads produce a variety of calls, and call quite frequently. The functional importance of some of these calls has been documented in a general way (Würsig et al. 1982, 1983). Increased background noise levels at low frequencies will decrease the signal to noise ratio and reduce the range to which a call will be detectable. With spherical spreading*, a 20 dB increase in noise level, which is not uncommon, will reduce the range of detectability by a factor of 10, e.g., from 10 km to 1 km. A 40 dB increase in noise level could cause a 100-fold reduction in communication range.

The biological significance of a reduction in communication range is uncertain. We do not know how important it is for distant bowheads to hear one another. However, the characteristics of bowhead calls strongly suggest that they function over distances of many kilometres. Increased noise levels as a result of industrial activity will be more important if bowheads often communicate over many kilometres than if they normally do so only over a kilometre or so. Natural noise levels in the sea vary widely. Bowheads must be adapted to occasional increases in ambient noise levels. Nonetheless, elevated noise levels will inevitably reduce the potential range of communication. This could be important if long-range communication by sound is important to bowheads.

A study of short-term behavioral reactions also does not allow a direct assessment of long-term effects. However, it can provide some of the information needed to determine whether there are year-to-year changes in distribution that may be attributable to industrial activity (Richardson et al. 1983a). It can also provide clues regarding the types of industrial stimuli that are most likely to have long-term effects. One could hypothesize that the stimuli most likely to have long-term effects are the ones to which there is a strong short-term reaction. This would be especially likely if the short-term reaction involved mating animals or mother-calf pairs, since disturbance to those whales could have direct effects on reproduction and recruitment.

Applicability to Alaska

The applicability of our results to bowheads in Alaskan waters remains a topic of concern. Our 1982 data, as well as the 1980-81 results, were obtained in the eastern Beaufort Sea in mid to late summer. At this time

* With spherical spreading, received level decreases by 20 dB per 10-fold increase in range.

bowheads are feeding, socializing and, on an intermittent basis, travelling considerable distances. Most of the whales studied were in open water, although pan ice was nearby on some occasions. Behavior of bowheads in the Alaskan Beaufort Sea during late summer and early autumn (until late September) appears very similar (Braham et al. 1977; Ljungblad et al. 1980; Lowry and Burns 1980; Ljungblad 1981, pers. comm.). Also, some of our results were obtained off the Yukon coast, not far from Alaskan waters. This included all of our 1982 results concerning seismic noise as well as the drillship noise playback experiments. We suspect that the reactions of whales in the Alaskan Beaufort Sea up to late September would be similar to what we have observed.

Later in the autumn, bowheads begin to travel more consistently to the west through Alaskan waters (Ljungblad et al. 1980; Ljungblad 1981, pers. comm.). Our results may be less applicable to these actively travelling whales. Similarly, it is uncertain how similar the reactions of bowheads would be during the winter and spring, when their activities differ considerably from those in summer and when the whales are usually in or near pack ice. If detection of sounds from ice or other bowheads far away is important during migration (e.g., to find openings in ice), industrial noise along migration routes might have effects of types that this study could not detect.

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CHARACTERISTICS OF WATERBORNE INDUSTRIAL NOISE, 1982 *

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ABSTRACT

Underwater sounds in the eastern Beaufort Sea were studied during August 1982 as part of a continuing project to study the behavior of bowhead whales in areas of offshore hydrocarbon exploration and development. Similar studies in 1980-81 had included measurements of underwater noise from a drillship, a suction dredge, a loaded hopper dredge underway, three types of aircraft (Twin Otter, Britten-Norman Islander, Bell 212 helicopter), several support vessels, and seismic survey signals from sleeve exploders. Models

for sound transmission loss in the shallow water were also derived. In 1982, measurements were made of seismic signals at close ranges (from 0.9-14.8 km), seismic signals from an airgun array at ranges of 52-75 km, sounds from a variety of activities at an artificial island (Tarsiut), sounds from a different drillship, and sounds from trailing suction hopper dredges dropping and picking up loads.

Sounds were recorded via sonobuoys dropped from an Islander aircraft and via hydrophones deployed beneath a sparbuoy floating near a drifting vessel--the MV 'Sequel', a former fishing boat. In addition, previously recorded drillship sounds were projected underwater near bowheads in playback experiments to study any behavior changes that might occur.

The **seismic ship** 'Arctic Surveyor' used open-bottom gas guns in 1982. For ranges 0.9 to 14.8 km in water 9-11 m deep we recorded peak levels corresponding to rms levels from 177 to 123 dB//1 μPa. Using a least squares regression fit to an equation with a spherical spreading loss term of 20 log(R), we derived an absorption loss term of 2.09 dB/km and a predicted level of 174.5 dB//1 μPa at 1 km; the standard error was 1.7 dB. Frequency content at the short ranges (to 1.9 km) was predominantly below 150 Hz; beyond 7.4 km the energy was predominantly above 150 Hz. Thus, low frequencies attenuated more rapidly in the shallow water. The low frequency energy (<100 Hz) probably travelled via a higher-velocity sub-bottom path; it arrived 70-135 ms (depending on range) before the higher frequency component, which presumably travelled via an in-water path.

Signals received from the 1410 cu in airgun array on 'GSI Mariner' varied considerably over short periods of time, but we recorded levels from 133 dB at 60 km to 110 db at 75 km. Transmission loss could not be modeled because data were recorded sporadically at different places and times.

Tarsiut Island was a caisson-retained **artificial island** in 23 m of water off the Mackenzie Delta. During two visits by 'Sequel', there were always four or more workboats, barges and tugs in the vicinity. Drilling had been completed before our first visit on 6 August, but different activities contributed to varying noise levels. Sounds from pile driving using a vibrator on the opposite corner of Tarsiut from "Sequel's" position were not identified. At 1.1 km on two occasions, band levels for 10-500 Hz varied from 126-133 dB//1 µPa and there were several strong tones (e.g., 55 Hz at 113 dB, 115 Hz at 116 dB, and 132 Hz at 119 dB). At 0.46 km, the 10-500 Hz band level was 119 dB and the strong tones were 91 Hz at 104 dB and 121 Hz at 112 dB. It is not known which of the various noise sources in the area was responsible for each of these tones. Noise recorded 18.5 km west of Tarsiut 3 h later was generally indistingishable from natural ambient noise--the 10-500 Hz band level was 104 dB or 15 dB lower than 0.46 km from Tarsiut.

Drillship 'Explorer I' was never drilling during our two visits in 'Sequel' but other drillship sounds were recorded at two short ranges. Water depth was 17 m and the ship was about 18 km east of Tarsiut Island. While the drillship was 'logging', we measured a 10-500 Hz band level of 125 dB at a range of 170 m. The noise spectrum included several strong tones, including 88 Hz at 112 dB, 211 Hz at 118 dB, and 501 Hz at 108 dB. At 610 m, the 10-500 Hz band level was 113 dB and the strongest tone was at 88 Hz, 103 dB.

Sonobuoy recordings at ranges of 11 and 18.5 km from drillship 'Explorer III' while drilling showed no evidence of machinery noise.

Sounds of the **hopper dredge** 'Gateway' dropping her load in 12 m of water were recorded at a range of 1.5 km. The 10-500 Hz band level was 129 dB. Underway empty at a range of 1.06 km the level in the same band was also 129 dB. While stopped and not dumping at range 1.5 km, the 10-500 Hz band level was 120 dB. Hopper dredge 'Geopotes X' picking up a load at a range of 0.43 km produced a 10-500 Hz band level of 141 dB. We estimated that, at a standardized range of 1 km, 'Geopotes X' dredging was 5 dB noisier than 'Gateway' dumping (in the 10-500 Hz band).

The projected drillship sounds during the highest-level **playback experiment** achieved a maximum source level of 164 dB//1 µPa-m. At range 2 km, the 10-500 Hz band level was 109 dB and the dominant 275 Hz tone was 103 dB. Based on the drillship transmission loss model developed in 1981 for this tone, a level of 103 dB would be expected at a range of 7 km from the

INTRODUCTION

One of the primary concerns regarding potential environmental effects of offshore exploration and development of hydrocarbon deposits is the possible effect of underwater noise on marine mammals. Noises of concern include those from vessels, aircraft, dredges, drilling, and geophysical surveys using sources of impulsive underwater sound (seismic surveys). Among other projects, the Minerals Management Service, U.S. Department of the Interior, has sponsored our studies of the responses of bowhead whales to offshore oil exploration. This research has been done in the eastern Beaufort Sea where the Western Arctic stock of bowhead whales feed throughout the summer. Canadian oil companies have been operating offshore in this area for several years. Under the project, we have measured noises from a variety of industrial sources during August of 1980-82 while biologists studied whale behavior in the presence and absence of these same industrial activities (Richardson 1982 and this volume).

Characteristics of industrial sounds recorded in 1980-81 were described by Greene (1982). That report also summarizes previous literature concerning noise from offshore hydrocarbon exploration. The present report concerns primarily the sounds recorded in 1982.

For the 1982 effort, Polar Research Laboratory, Inc., again provided the acoustic instrumentation for an aircraft and a boat, provided an acoustician for the boat crew, and analyzed the industrial sounds recorded during the field work. The aircraft instrumentation consisted of a supply of AN/SSQ-57A sonobuoys, two sonobuoy receivers, and a two-channel cassette recorder. On the boat, the MV 'Sequel', we had equipment for two types of tasks. To record noises, there were two low noise hydrophones (one for low frequencies and the second for wideband reception), amplifiers, and a two-channel cassette recorder. To broadcast underwater sounds near whales, we used a one watt underwater sound projector, power amplifier, monitor hydrophone, and other monitoring instruments. The latter instrumentation was used for experiments in which previously recorded industrial sounds were played back near whales while observers in the aircraft and on the boat monitored bowhead behavior.

The approach to measuring industrial sounds was primarily opportunistic. When not committed to an experiment in coordination with the aircraft, the 'Sequel' would cruise to a known area of industrial activity. We talked to the operators by VHF radio, if possible, to determine what was happening and to avoid being in the way. In August 1982 we were able to record sounds of seismic survey work by 'Arctic Surveyor' and 'GSI Mariner'; sounds from the drillship 'Explorer I' while it was logging; sounds from the hopper dredge 'Gateway' while dumping her load and from the hopper dredge 'Geopotes X' while picking up a load; and sounds from the artificial island Tarsiut while pile driving was occurring.

Playback experiments were more difficult. It was necessary that bowheads, airplane, boat, and good weather (low wind, no fog) all be present at the same time. An additional requirement was that there be no bowhead calves present, as our permit precluded us from conducting disturbance trials with calves. During playback experiments, the airplane crew deployed a sonobuoy about 2 km from the boat, and the boat crew deployed the projector over the side in order to ensonify the ocean with drillship sounds. The details of playback experiments are presented in Richardson et al. (1983c); this report provides background information about the characteristics of the projected sounds.

The operating area and main sound recording sites are shown in Figure 1.

METHODS

The methods used in 1982 were similar to those used in 1981 (Greene 1982) and will be described here only in summary.

Aircraft System

Sonobuoys were the means by which the aircraft recorded waterborne sounds. In 1982, we used AN/SSQ-57A buoys manufactured by Hermes Electronics, and the sonobuoy hydrophones were always set to deploy to 18 m depth. These sonobuoys are delivered with calibration data, although the specification allows a deviation of 2 dB either way.

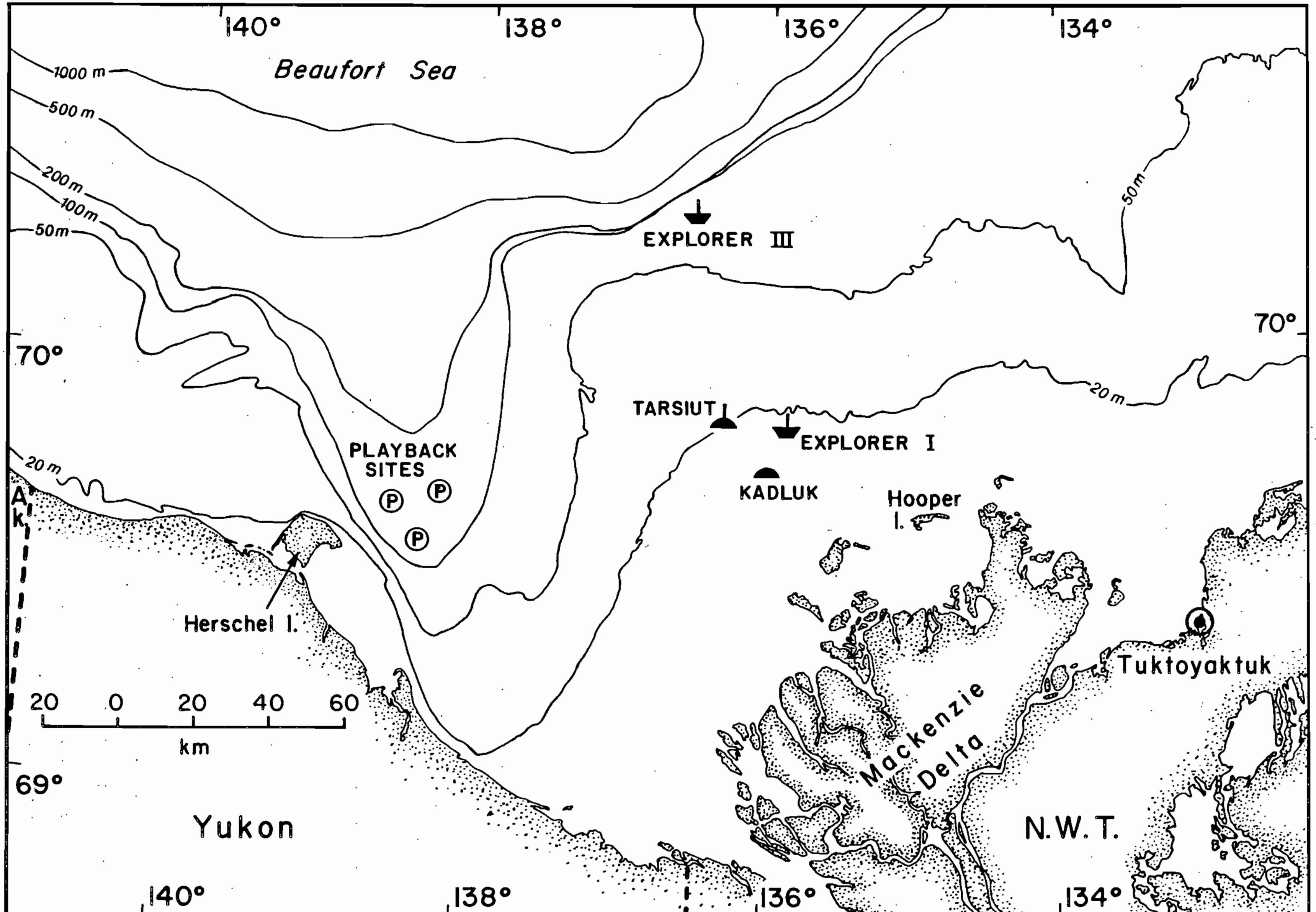


FIGURE 1. Map of the study area, east-central Beaufort Sea. Water depths and some of the major recording sites in 1982 are shown.

The receiving and recording system on the aircraft was the same as in 1981 (Greene 1982). The receivers were portable FM radios with frequency converters to allow the sonobuoy radio frequencies to be tuned. The receiver sensitivities were calibrated to permit computation of sound pressures in the water in units of microPascals. A Sony model TC-D5M stereo cassette recorder with servo controlled capstan drive (for precise control of tape speed) was used to record the signals.

Sonobuoys do not have flat responses; low frequencies are de-emphasized and high frequencies are emphasized. Hence, the waveforms recorded are not faithful analogs of the sound pressure waveform at the sonobuoy hydrophone. However, the calibration curve showing sonobuoy sensitivity as a function of frequency allows us to compensate for this uneven response while we are computing the noise power density spectrum. All power spectra for sounds recorded via sonobuoys have been corrected in this way both in this report and in Greene (1982). A filter on the radio output having the inverse frequency response--emphasis at low frequencies and de-emphasis at high frequencies--could also be used to restore the waveform to the shape of the signals at the hydrophone.

Boat System

Two hydrophones were used. The wideband hydrophone on the boat was a model H56 reference hydrophone from the U.S. Navy Underwater Sound Reference Detachment, Orlando (Naval Res. Lab. 1982). The H56 has a calibrated response from 10 to 65,000 Hz and a built-in low noise preamplifier. The separate low frequency hydrophone used a bender element and had a uniform response from 5 to >1000 Hz. Its built-in preamplifier is designed to produce very little self-noise at low frequencies. Separate postamplifiers for both hydrophones allowed the investigator to select an optimum gain for the signals being recorded. For commonality with the 1981 data and to allow for the expected shallow water, the usual depth of these two hydrophones was 9 m.

The projector used for playback experiments was USRD's model J-11. We deployed it from 'Sequel' at a depth of 9 m. A monitor hydrophone (we used source level. During playback experiments, an endless loop cassette tape with a recording of the industrial noise was played through a 250 watt amplifier. In 1982, all playbacks involved recorded noise from the drillship 'Explorer II', but we also had loops with noise from a dredge and from drilling on an icebound island. The waveform from the H56 hydrophone was monitored to prevent distortion due to overdriving the projector, and an rms voltmeter provided signal level information. Noise detected by a sonobuoy some 1.5-2 km away was recorded aboard the observation aircraft circling overhead; this provided information on the levels of sound near bowheads.

The distances from 'Sequel' to industrial sources were usually determined by radar on 'Sequel'. The location of the 'Sequel' was determined by a navigation satellite receiver and, less precisely, by the VLF navigation system on the observation aircraft when it passed overhead. Distances to distant seismic vessels were sometimes determined from the known positions of the seismic vessel and 'Sequel'.

Data Analysis

The core of the acoustic data analysis process is an analog-to-digital converter in a NOVA 3/12 minicomputer at PRL. The digitized data are needed to compute power spectra, spectrograms (frequency vs. time plots), and intensity vs. time plots.

A segment of taped noise to be digitized is low-pass filtered, amplified, converted to 12 bit words in the computer, and stored on disk. The process is flexible, but as a rule we save 17,408 samples in a file for each segment to be analyzed. Various sampling frequencies differing by powers of two are used. This leads to integer spacing of the frequency 'cells' or 'bins' resulting from discrete Fourier analysis in power spectral density computations (Table 1). For the first two sample frequencies the analysis is done with blocks of 2048 samples for each transform; for the higher two sample rates the transform block size is 1024. That is why the bin spacing and effective bin width jump by an extra factor of two between 4096 and 8192 samples/second. The 4096 Hz rate was only used on the Britten-Norman (B-N) Islander flyover analyses, where we desired a segment length of only 4 s.

Table 1. Attributes of power spectrum analyses with different sampling rates.

Length of Sample Frequency	Bin Spacing	Effective Bin Width	Filter Cutoff	Record Analyzed
2048 Hz	1 Hz	1.7 Hz	1000 Hz	8.5 s
4096	2	3.4	2000	4.25
8192	8	13.6	4000	2.125
16384	16	27.2	8000	1.0625

Previous to 1982 (Greene 1982, p. 271), we had computed power spectra to 500 Hz with 2 Hz bin spacing and to 1000 Hz with 4 Hz spacing using independent computations. By sampling the 1982 data at 2048 Hz and using a transform block size of 2048 samples, we achieved a 1 Hz bin spacing to 1000 Hz, thereby both enhancing resolution and saving considerable computing time. To retain compatible plots, we plotted 0-500 Hz and 500-1000 Hz in separate graphs. The total length of each 1982 data segment analyzed was increased from the 16,384 samples of 1981 to 17,408 to allow the computation of the last (the 8th) 50% overlapped block of data.

In computing the Fourier transforms, a 'window' is applied to the samples in the block to assure isolation of the results in one bin from those in another (Harris 1978). Without such windowing a strong tone in one bin may 'leak' into adjacent bins, obscuring weaker tones. The price of this windowing is wider effective bin widths and reduced use of the data. The wider bins must be accepted but the lost data can be substantially recovered by analyzing overlapping blocks of samples. We used 50% overlaping so every sample is processed twice.

For sounds whose characteristics change rapidly, such as pulses of noise from seismic exploration, 'waterfall'-type spectrograms are desirable. In this case, power spectra are computed separately for many successive portions of the taped noise. Greene (1982) described the procedure.

The other analysis done with the digital samples is simply to plot them as time series. This permits examining waveforms and measuring amplitudes, which we needed to do with the seismic survey signals. For data recorded from the H56 hydrophone (on the boat), we could carry the calibrations through and plot the waveform in microPascals vs. time in seconds. For data recorded via sonobuoys, whose response is not uniform with frequency, we simply plot 'volts into the recorder' vs. time. The investigator must then determine what frequency dominates, either by counting the number of pressure cycles per second or by examining the computed spectrum for the signal.

In the Results we present spectra for the seismic signals. These require special interpretation. These spectra were computed and plotted in the same way as were signals from continuous sources, which presumes that the sound persists more or less uniformly throughout the segment of samples (17,408). Of course, this is not the case for the seismic signals. Thus, such spectral plots must be interpreted qualitatively, showing where in frequency the energy in the signals falls. They must not be taken literally as indicating that the spectrum level for a certain seismic signal at a certain frequency is so many dB//1 μPa2/Hz; it is not.

Band Levels. As part of the spectrum plotting process, we now integrate the spectrum levels in different bands of frequency to compute band levels. We use one half the spectrum levels in the end bins of a band, always choosing band limits that fall on bin centers. We generally present band levels for the 10 to 500 Hz band, computed from the 8.5 s segment of noise sampled at 2048 Hz and analyzed with 1 Hz bin spacing. Interestingly, only rarely did the level in the 10 to 1000 Hz band exceed the level in the 10 to 500 Hz band by as much as 1 dB; typically, it was only 0.1 dB more. Most energy, whether ambient or from industrial sources, is found at low frequencies.

Tones. Tones, or line components in a spectrum, are narrowband in character. Usually they are narrower than the analysis resolution. This being the case, the level of power computed for a bin containing a tone, in units dB//1 μPa, should not be converted to a power spectrum level in dB//1 μPa2/Hz. Our plotting program identifies spectral components greater than 3 dB above the preceding spectral minimum, removes the 'correction to 1 Hz', and prints the frequency and power. The investigator must determine if the peak was actually a tone. The spectrum plot is not changed, so the spectrum levels of tones are presented in all our spectra. Because of the change from spectrum level to power level, the plotted level in dB//1 $\mu Pa^2/Hz$ will always be less than the printed level in dB//1 μPa. The latter is the more useful figure.

Terminology. Specialized acoustic terminology used in this report is used in the same way as in Greene (1982). Pages 272-274 of that report define the acoustical terms.

RESULTS

This section is organized to present the results of the sound measurements and analyses by the type of source. We begin with a presentation of sound speed profiles and examples of ray paths, then proceed to some samples of ambient noise, and then present results for several industrial sources.

Sound Speed Profiles and Sound Ray Paths

Knowledge of sound ray paths is important in understanding sound propagation. Ray paths, in turn, are strongly influenced by the vertical profile of sound speed, which can be determined from the vertical profiles of temperature and salinity (Urick 1975).

Salinity, temperature, and depth profiles were measured to the bottom or to 38 m, whichever came first, at three places. A Hydrolab System 8000 instrument was used. At two of these locations the water depth was 110 m, and, ignorant of the actual salinity and temperature at the bottom in those cases, we assigned the same values as were measured at the end of our cable. The results are contained in Figure 2. In studying this figure, note that both the depth and range scales change for the three locations. The same source depth (9 m) and initial ray angles are used in all three examples of

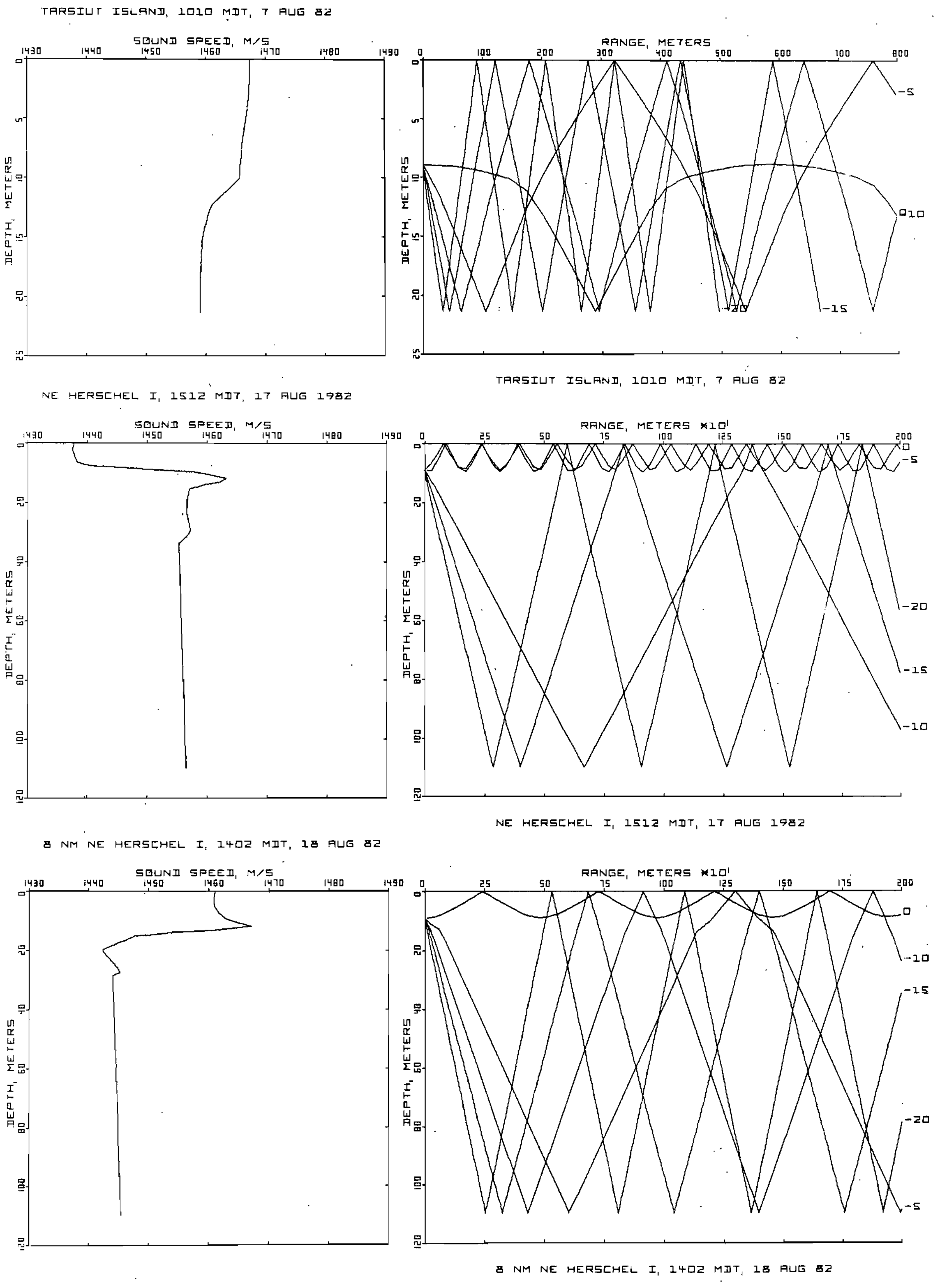


FIGURE 2. Sound speed profiles and sample ray paths at three sites, August 1982.

The top profile is for Tarsiut Island and is probably representative of the shallow water areas in which industry operates. It is similar to profiles measured previously in the shallow areas, although the negative gradient is less severe than we observed in 1980-81 (Greene 1982, p. 276-7). The bottom has a strong influence on sound propagation here.

The sharp positive gradient in the second example is not surprising, as we were anchored to a drifting ice floe in an area dominated by ice. A shallow surface channel exists, although this is not important at low frequencies. Because of the deeper water, bottom reflections may not be important at ranges up to a few kilometres.

The third example is for the same general area but without any ice; the profile is more typical of summer, with a warmer, higher speed layer near the surface. High frequency sound from near the surface will tend to travel in a shallow surface duct while deeper sources will radiate with strong downward refraction for depths in the negative gradient.

Ambient Noise

No comprehensive study of ambient noise was possible within the project, but background noise was recorded on numerous occasions, both with the sonobuoys and with the hydrophones on 'Sequel'. Four examples that are generally representative of situations encountered in 1982 are illustrated here. The circumstances of these recordings are summarized in Table 2.

Figure 3 presents spectra for noise picked up by a sonobuoy 6 n.mi. (11 km) from the drillship 'Explorer III', which was drilling at the time. There is little in the spectrum to suggest any man-made noise other than the two small tones between 2500 and 3000 Hz. These spectra represent ambient noise for the most part. The 10-500 Hz band level is 100.7 dB. Behavior of whales near this sonobuoy is described in Richardson et al. (1983c).

Figure 4 presents spectra for noise from a sonobuoy drifting near an area of ice floes off Herschel Island. Ice cover in the area was about 10%. The noise of ice floes melting is conspicuous when heard in the air from a

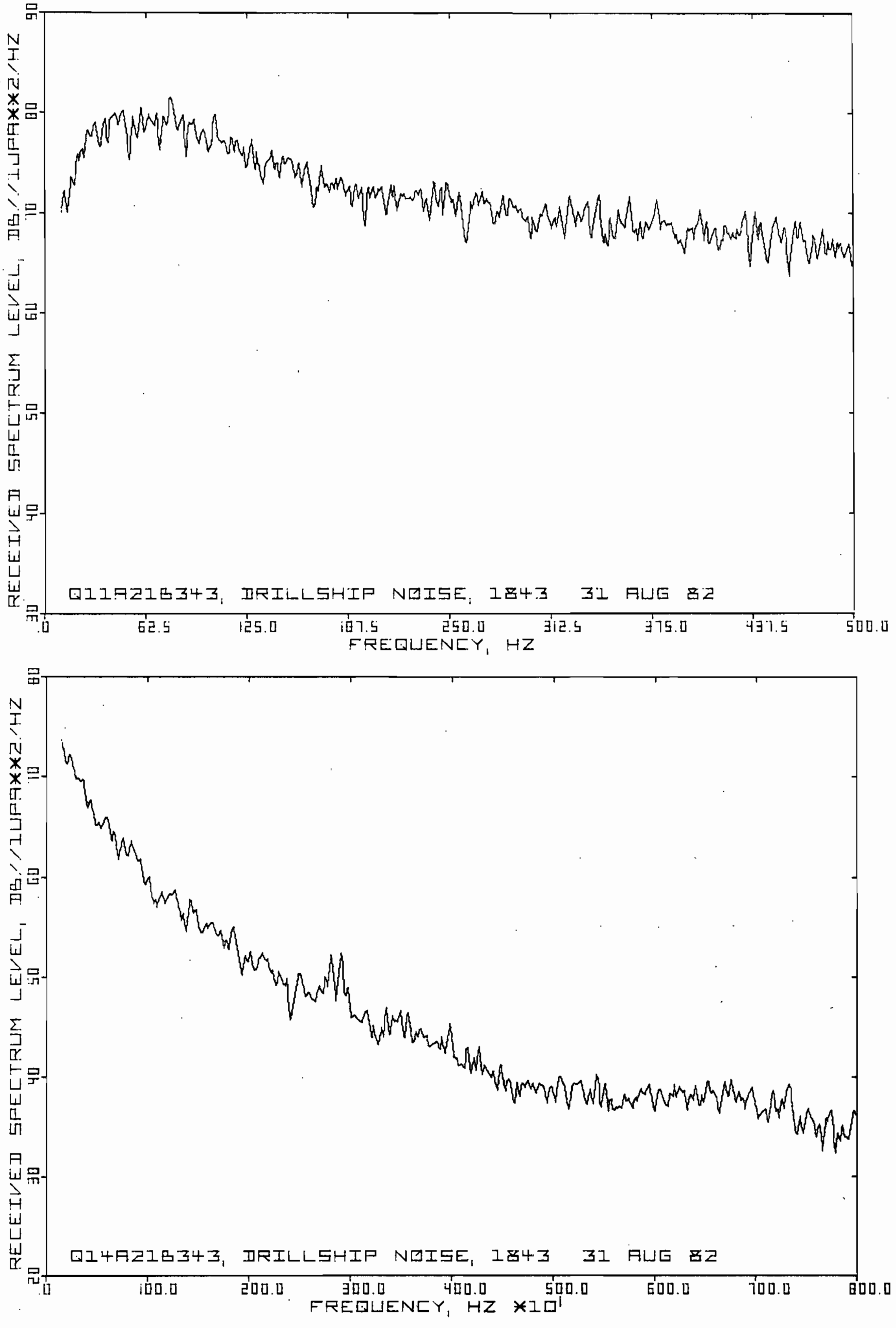
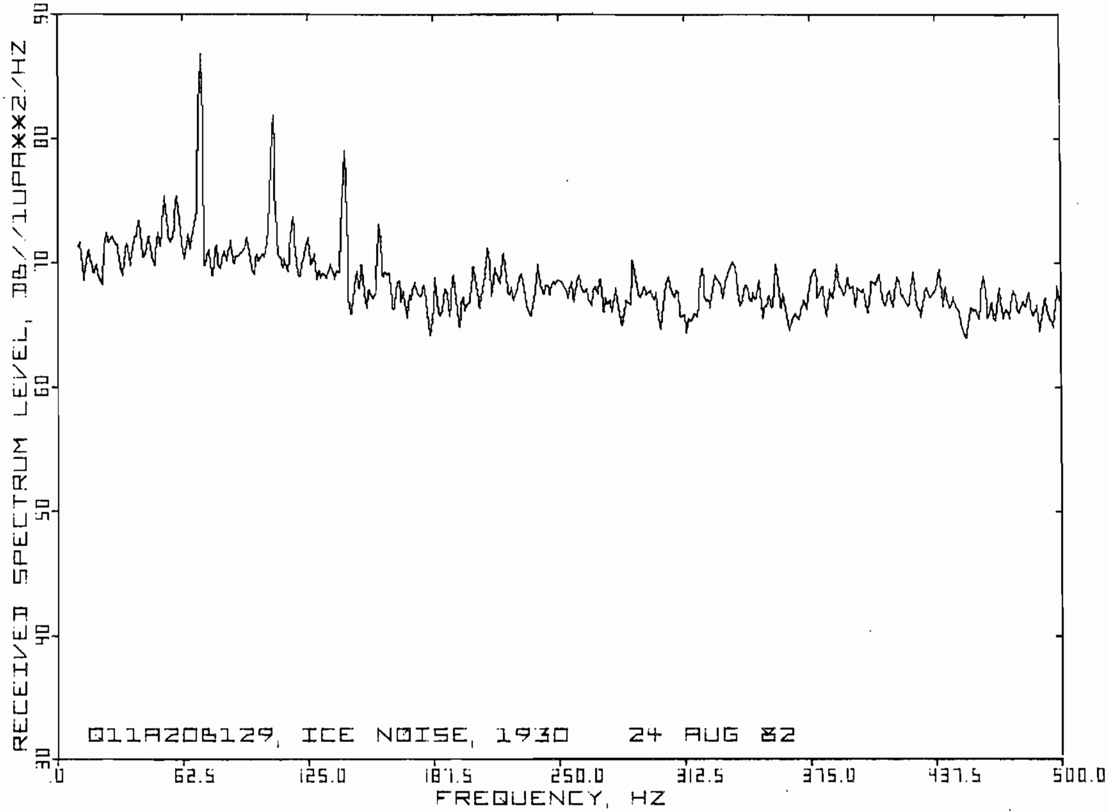


FIGURE 3. Ambient noise spectra 11 km (6 n.mi.) from the drillship 'Explorer III', 31 August 1982. Spectra for 10-500 Hz and 160-8000 Hz are shown.



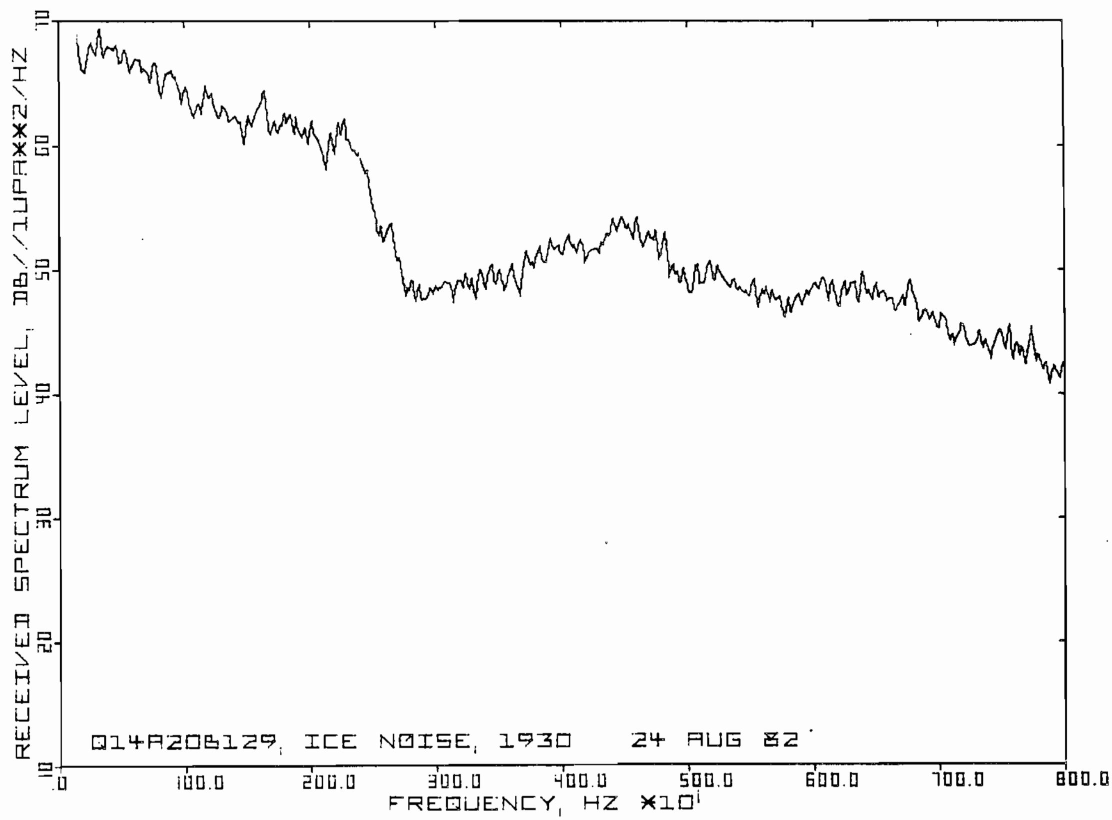


FIGURE 4. Ambient noise within an area of melting ice floes off

Table 2. Circumstances of the four recordings of ambient noise whose spectra appear in Figures 3-6.

Fig. No.	Date	Location	Water Depth	Sea State*	Ice Cover
3	31 Aug 1982	70°27'N 136°30'W	100 m	2	0%
4	24 Aug 1982	69°35'N 138°34'W	80	0	10
5	18 Aug 1982	69°36'N 138°22'W	120	1	0
6	15 Aug 1982	69"50'N 136°48'W	27	2	0

* 0 = calm, 1 = rippled, 2 = small wavelets, not breaking.

quiet, drifting boat. The tones at 72 Hz (89 dB), 108, 144, and 161 Hz are from the B-N Islander flying in the vicinity. The 10-500 Hz band level is 97.0 dB. If the three 1-Hz bins including the three prominent tones are excluded, the 10-500 Hz band level is 95.8 dB.

Figure 5 presents spectra for ambient noise recorded via sonobuoy during the intervals between the arrivals of seismic survey signals. This segment of tape was analyzed because a drilling noise playback experiment had just been completed (Richardson et al. 1983c). To prevent overloading the tape recorder by the seismic signals, the record level was set very low; as a result, the power line hum in the amplifier in the low pass filter appears in the resulting spectrum, along with two harmonics. These are not components of the ambient noise. The 10-500 Hz band level is 102.1 dB, or 101.3 dB if the three tones are excluded.

Figure 6 presents spectra of signals recorded on 'Sequel' 10 n.mi. (19 km) west of Tarsiut Island. Other than the strength of the possible tone at 16 Hz (96 dB), most of this noise is probably natural background. The 10-500 Hz band level is 103.5 dB.

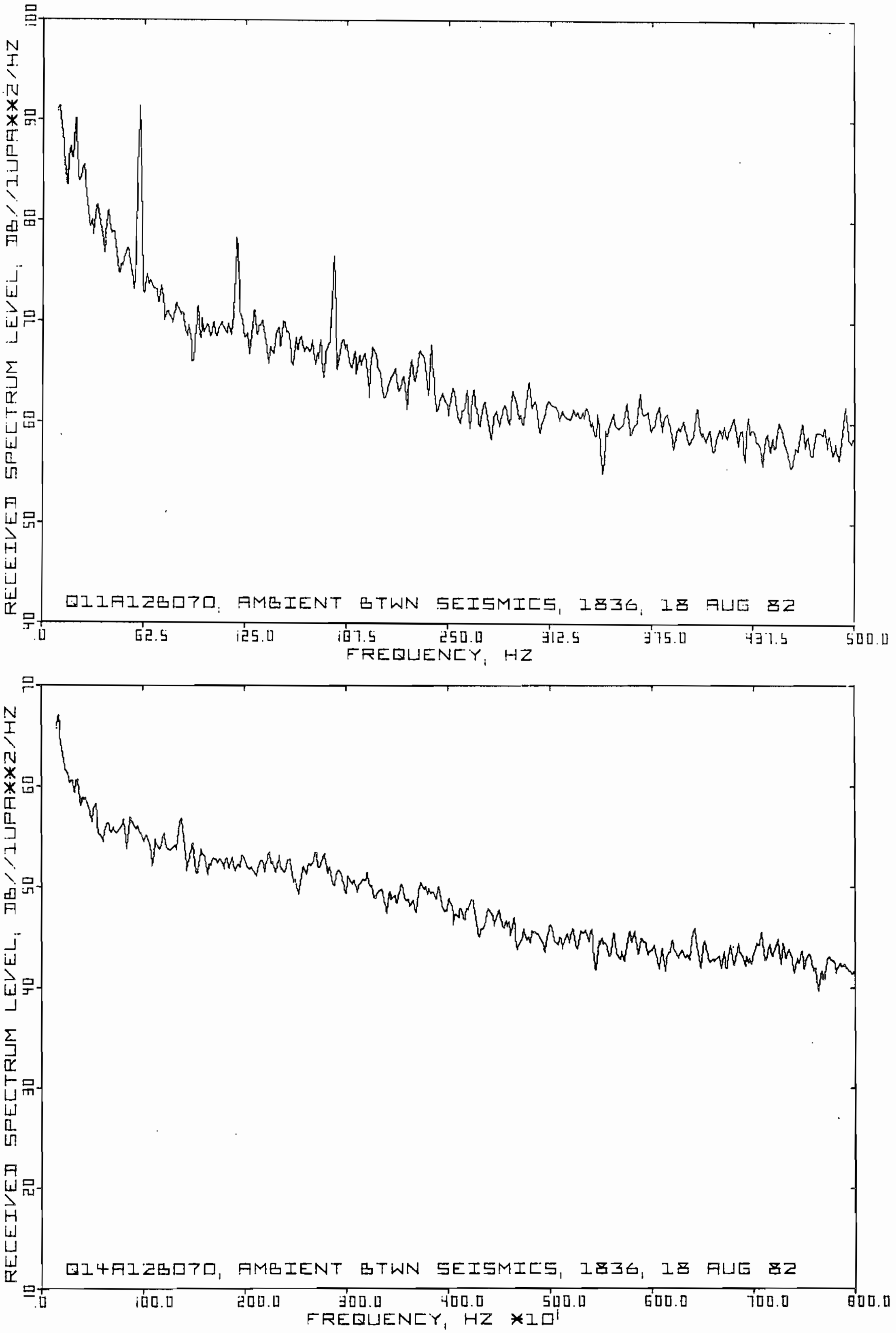


FIGURE 5. Ambient noise between seismic signals, 18 August 1982.

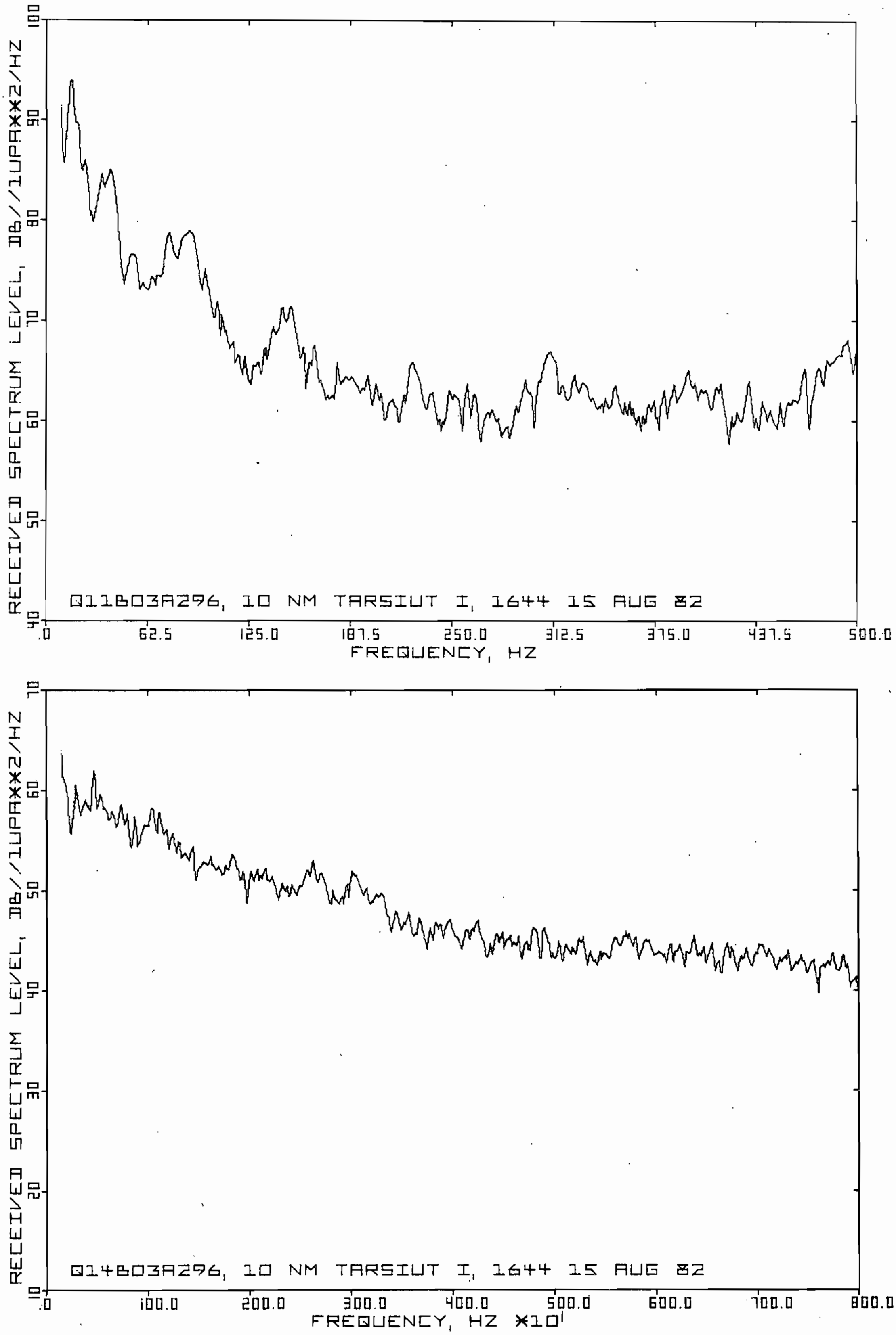


FIGURE 6. Ambient noise 19 km (10 n.mi.) west of Tarsiut Island, 15 August 1982.

Seismic Survey Signals

During 1982, seismic signals from two sources were recorded; from 'GSI Mariner', which was using an airgun array of 1410 cu in, and from 'Arctic Surveyor', which was using an array of open-bottom gas guns.

'Arctic Surveyor'

We had recorded signals from the sleeve exploders on 'Arctic Surveyor' at ranges between 8 and 28 km during 1981 and wanted to extend our knowledge of the signals to shorter ranges. However, in 1982 the operators (Esso Resources) had changed to open-bottom gas guns in the expectation of achieving 50% more source amplitude. During August, she was operating in the very shallow water (9 m) north of Hooper Island, and on 11 August we recorded her signals at six ranges from 0.9 to 14.8 km. The sounds of the thrusters operating when 'Surveyor' moved ahead between stations were clearly audible when listening to the hydrophone signals.

Figures 7-9 present the time waveforms and the corresponding spectra for signals received at six ranges between 0.9 and 14.8 km. The received spectrum levels shown in these Figures are meaningful in a relative but not an absolute sense (see Methods). Figure 8 shows a low frequency 'precursor' that was received at ranges up to 3.7 km but not at longer ranges. This low frequency component apparently arrived via a sub-bottom path with a higher velocity than exists for the water path. This bottom path is not manifest in the waveforms for the 7.4 and 14.8 km ranges shown in Fig. 9. 'Sequel' followed a track northeast from 'Surveyor' in obtaining these data, and evidently we crossed a geological discontinuity between the 3.7 and 7.4 km stations. We were unable to record signals at longer ranges because 'Surveyor' stopped operations when a personnel boat came alongside, and later the sea became too rough for sound recording.

Figure 10 contains spectrograms for the same six signals shown in Figures 7-9. At the shortest ranges, the received signal was dominated by low frequency energy (<150 Hz). However, after propagating 1.9 km, higher frequencies comprised a larger fraction of the remaining energy. Apparently

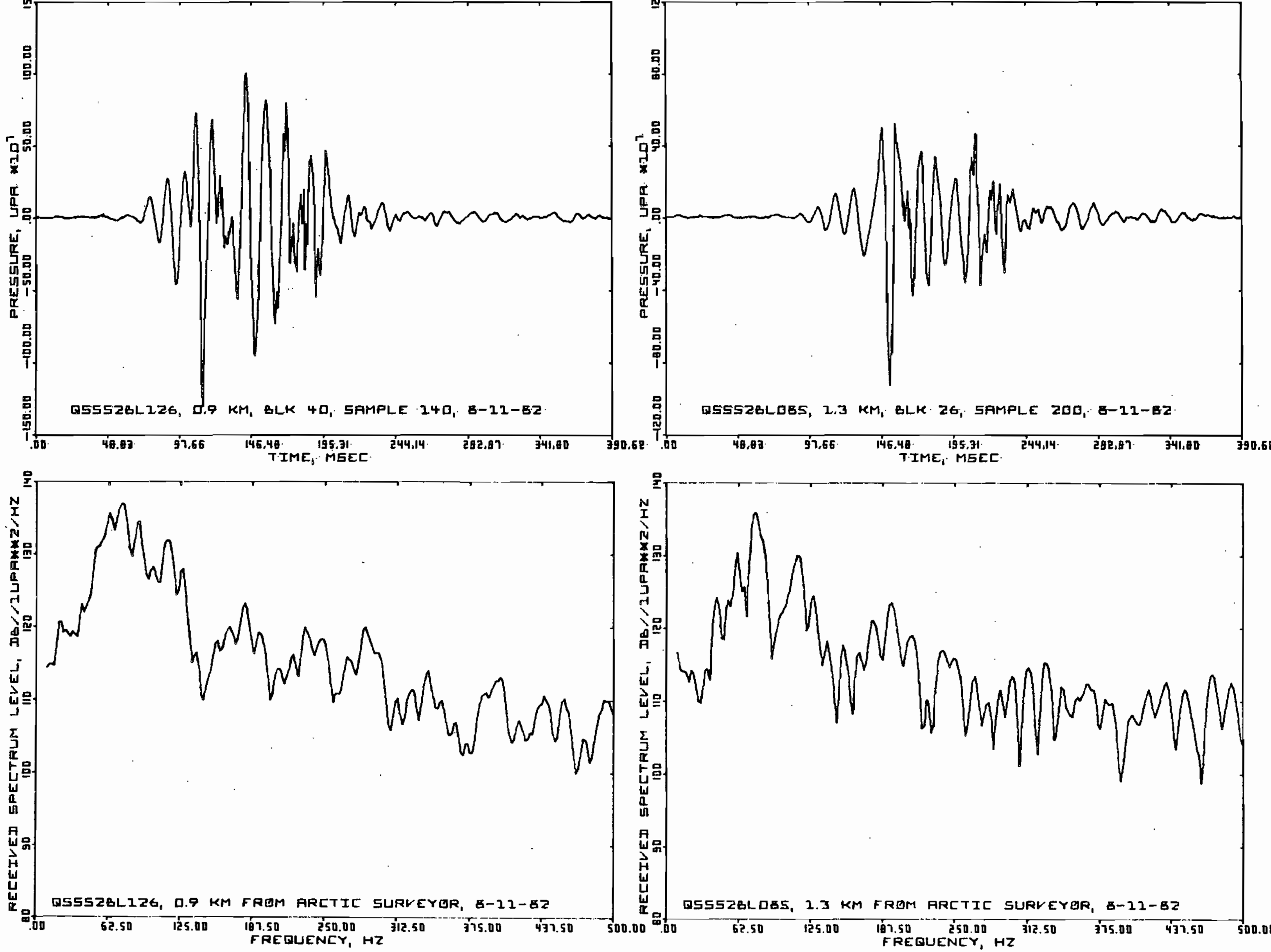


FIGURE 7. Waveforms and spectra for seismic signals at ranges of 0.9 and 1.3 km from 'Arctic Surveyor'. Received spectrum levels are meaningful in a relative but not an absolute sense (see Methods).

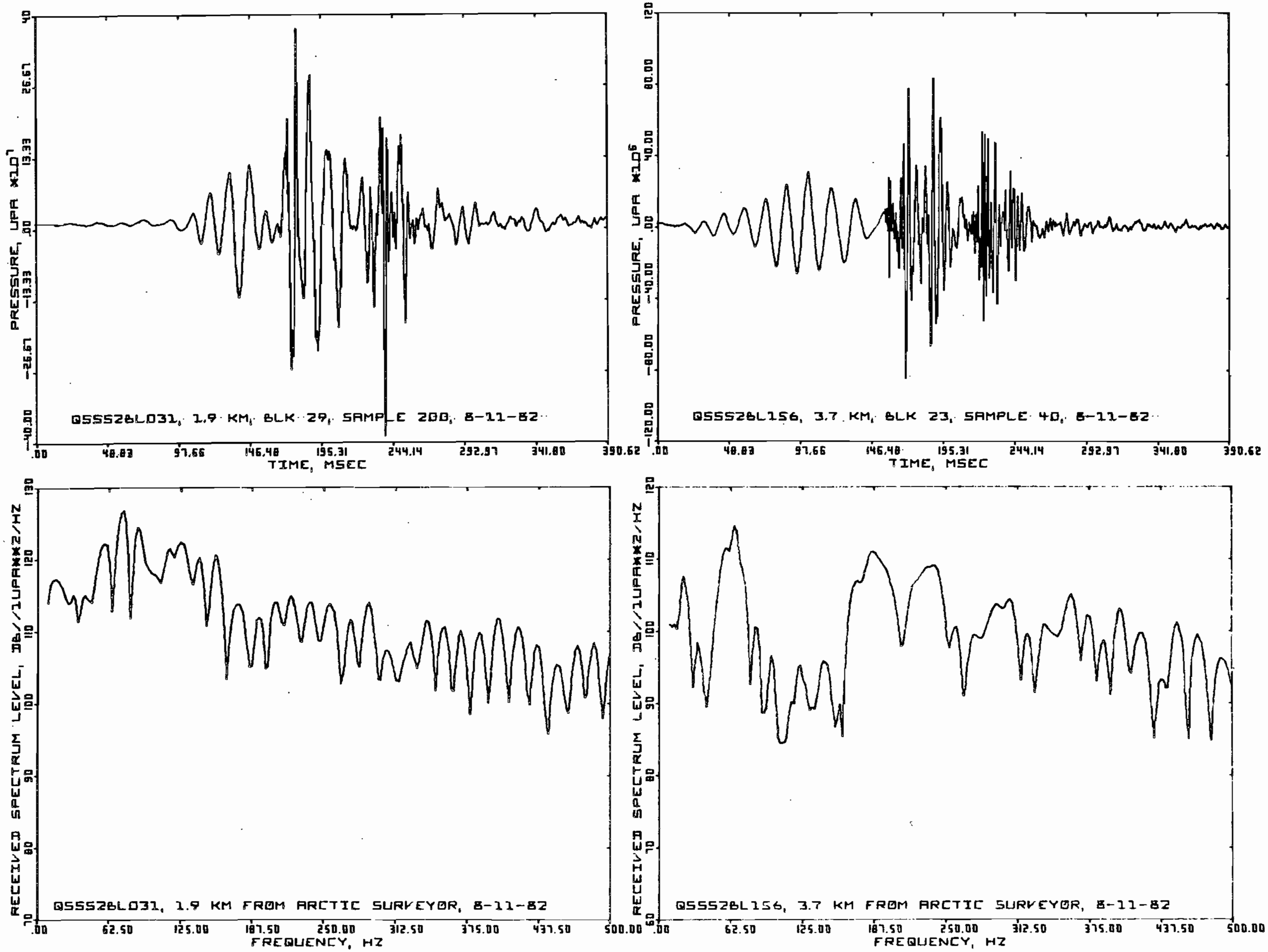


FIGURE 8. Waveforms and spectra for seismic signals at ranges of 1.9 and 3.7 km from 'Arctic Surveyor'.

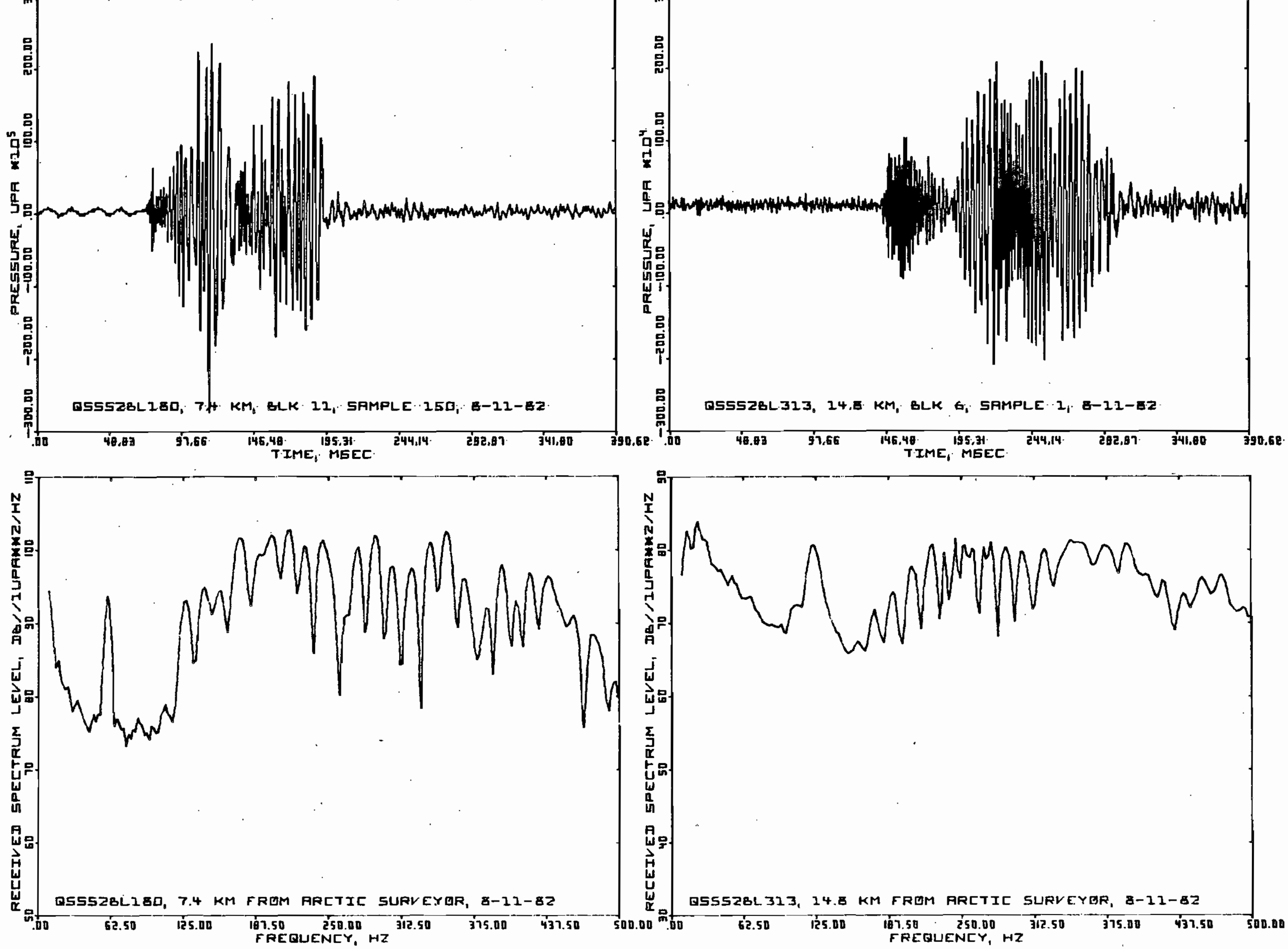


FIGURE 9. Waveforms and spectra for seismic signals at ranges of 7.4 and 14.8 km from 'Arctic Surveyor'.

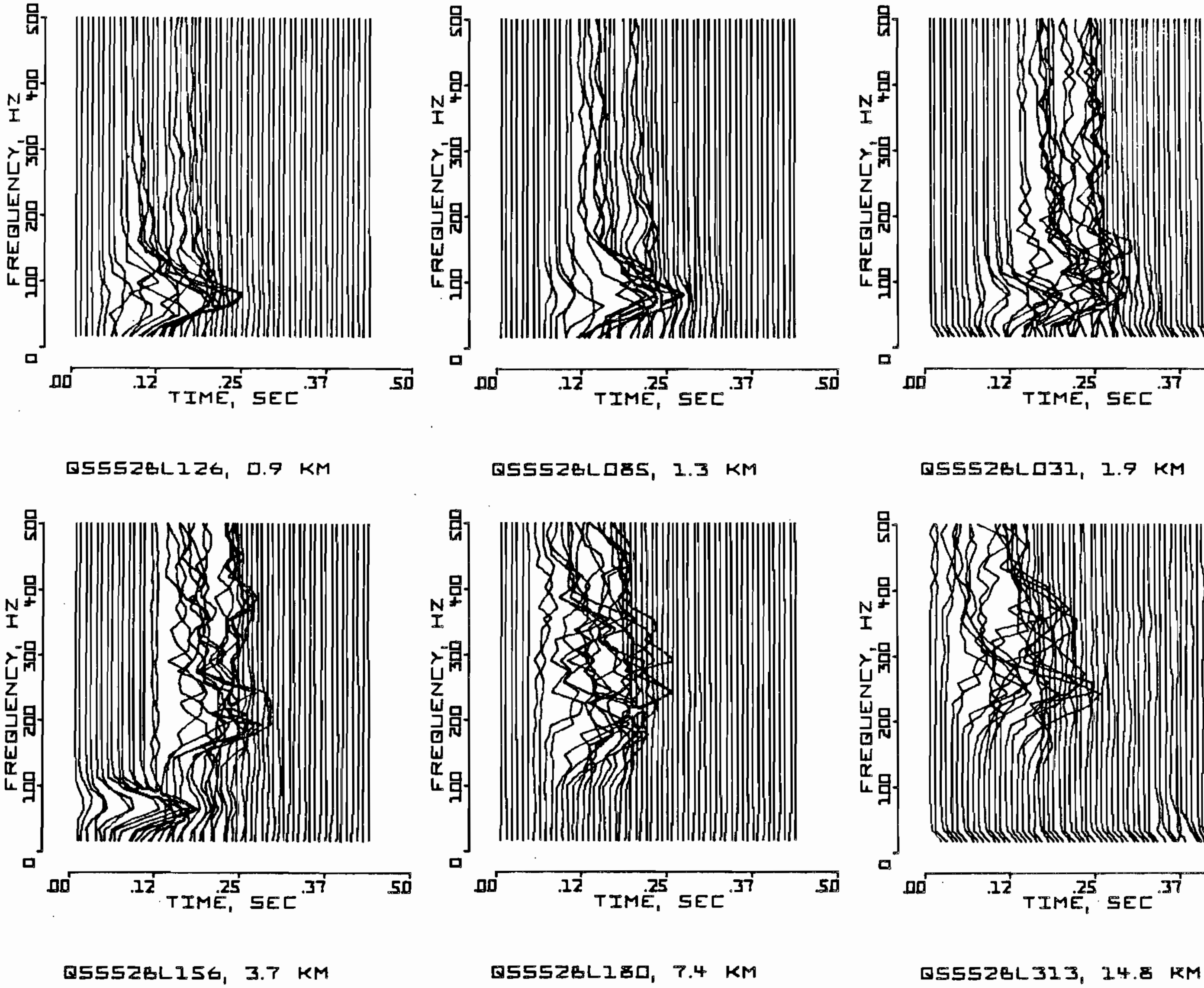


FIGURE 10. Spectrograms for seismic signals at six ranges from 0.9 to 14.8 km from 'Arctic Surveyor', 11 August 1982.

the low frequencies attenuated more rapidly than the higher frequencies. By 7.4 km, virtually all of the remaining energy was at frequencies above 150 Hz. As noted above, at ranges where both the low and the higher frequencies were evident (1.3-3.7 km), the low frequency component arrived first, probably via a bottom path. However, at 14.8 km, there was some indication that the earliest-arriving energy was at somewhat higher frequency (200-500 Hz) than the later-arriving energy (130-400 Hz). This downward trend in frequency was also noted for signals received at long ranges in 1980-81 (Greene 1982) and is characteristic of propagation in shallow water over ranges large enough for many reflected sound rays to combine at the receiver.

We converted the peak amplitudes from each of the time waveforms in Figures 7-9 into dB//1 µPa and fitted various equations for received level vs. range to the data. Least-squares regression methods were used. We treated the peak levels as though they were from continuous signals and used the corresponding rms values for amplitude. This artificiality does not detract from the potential benefits of finding a model that will reveal something about transmission loss for such signals in the shallow waters of the eastern Beaufort Sea. We had done this for the sleeve exploder signals over ranges from 8 to 28 km in 1981 and found a good fit to an equation with a spreading loss term of 10 log(R), where R is range in km, and an absorption loss term of 1.4 dB/km. The water depths for the 1981 data were 25-50 m. In 1982, the depths were only 9-11 m and we expected a greater absorption loss term to account for the increased effects of the surface and bottom.

Figure 11 shows the levels received in 1982 at six ranges, plus two of the fitted regression equations. The dashed curve is the result of the general regression, for which the spreading loss term was 26.6 log(R) and the absorption coefficient was 1.55 dB/km. For this equation, the coefficient of determination was 0.9969; the standard error was 1.5 dB. If we force the spreading loss term to be 20 log(R), corresponding to spherical spreading, then the absorption coefficient becomes 2.09 dB/km, the coefficient of determination is 0.9812, and the standard error is 1.7 dB. The latter curve is shown by the solid line in Fig. 11. We have extended the curves slightly beyond the range of the data to span ranges from 0.5 to 25 km.

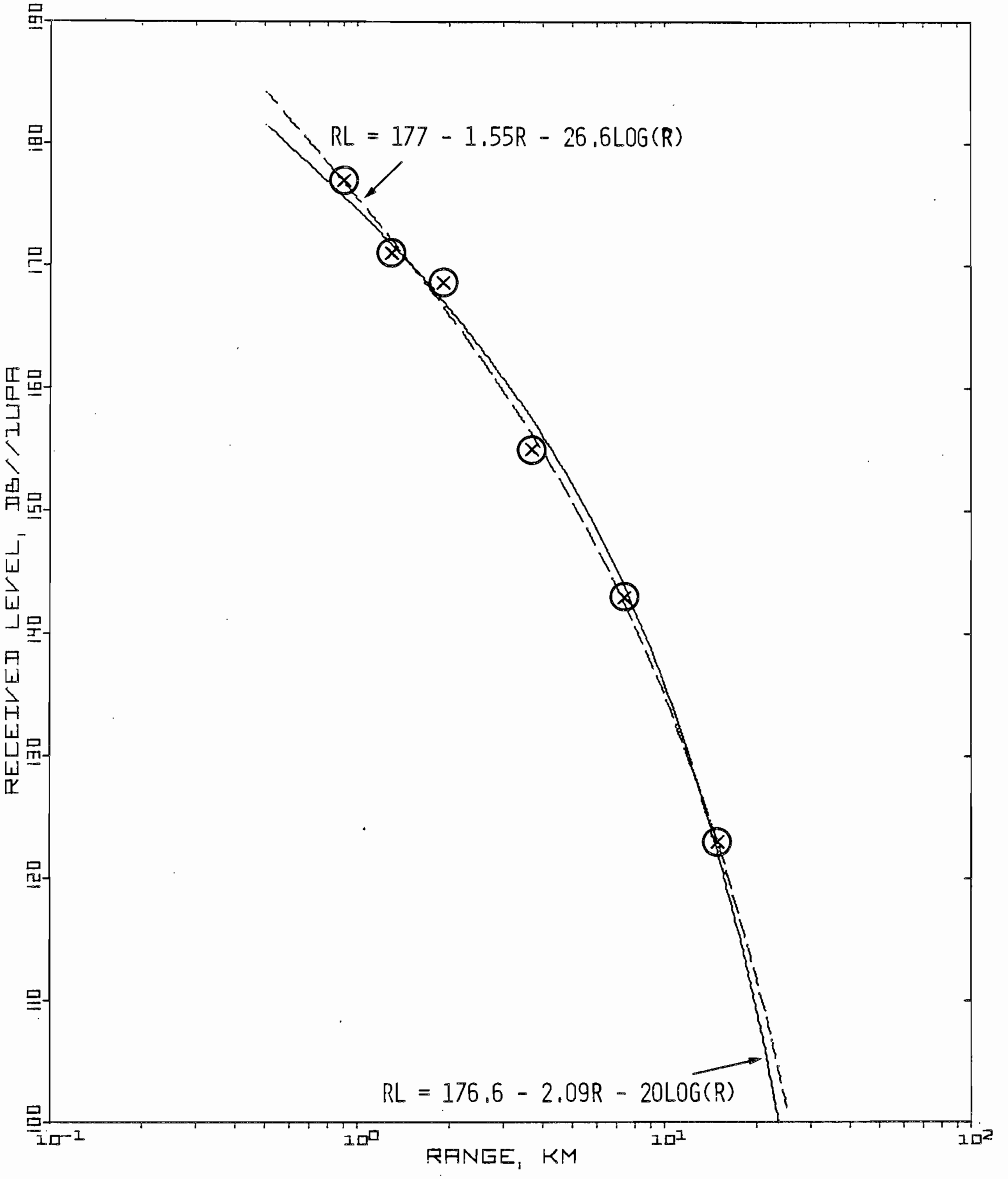


FIGURE 11. Received levels vs. log (range) for seismic survey signals from 'Arctic Surveyor', 11 August 1982. See text for discussion of fitted regression lines.

The very strong impulsive signal at the source travels non-linearly for some range until the so-called finite amplitude effects disappear and normal acoustic propagation begins. There are other difficulties in describing the signals at short ranges that relate to the interference of surface and bottom multipaths. Thus, we forced a 10 log(R) spreading loss term into another regression fit to the three long range data points--those for 3.7, 7.4 and 14.8 km. The result was an absorption coefficient of 2.33 dB/km, coefficient of determination of 0.9998, and a maximum prediction error of 0.22 dB. This equation is the one most directly comparable to the 1981 equation, which was based on data from ranges 8-28 km. The increase in absorption coefficient from 1.4 dB/km in 1981 to 2.33 dB/km can be explained by the shallower water in 1982. The result is useful in suggesting that cylindrical spreading can be assumed to occur at ranges beyond as little as 3 km for such shallow water. However, it is imperative that an appropriate absorption loss term also be used.

'GSI Mariner'

In August 1982, this ship was operating in the general area of Herschel Island and in the Alaskan Beaufort Sea (Richardson et al. 1983a). Her airgun array contained 27 guns of various sizes from 10 to 100 cu in; total gun volume was 1410 cu in, or 23 L (J. Stone, GSI, pers. comm. to W.J. Richardson). The interval between successive shots was typically 13-16 s. The source level of this array was 38 bar-m, peak to peak (G. Bartlett, GSI, pers. comm. to W.J.R.), or 246 dB//1 μPa-m.

We recorded signals from 'GSI Mariner' on numerous occasions in 1982, and some examples of waveforms are presented in Figure 12. The top two graphs are for signals recorded on 'Sequel'; using our technique of scaling the peak levels and converting to rms yields signal levels of 119 and 110 dB//1 μPa. The seismic ship was 52 and 75 km away, respectively, on these two occasions. The lower graphs come from signals received at a sonobuoy within 2 km from 'Sequel' on the same two days. As expected from the sensitivity characteristics of sonobuoys (see Methods), the lower diagrams emphasize high frequencies. Their peak levels are 128 and 126 dB for ranges of 54 and 66 km, respectively.

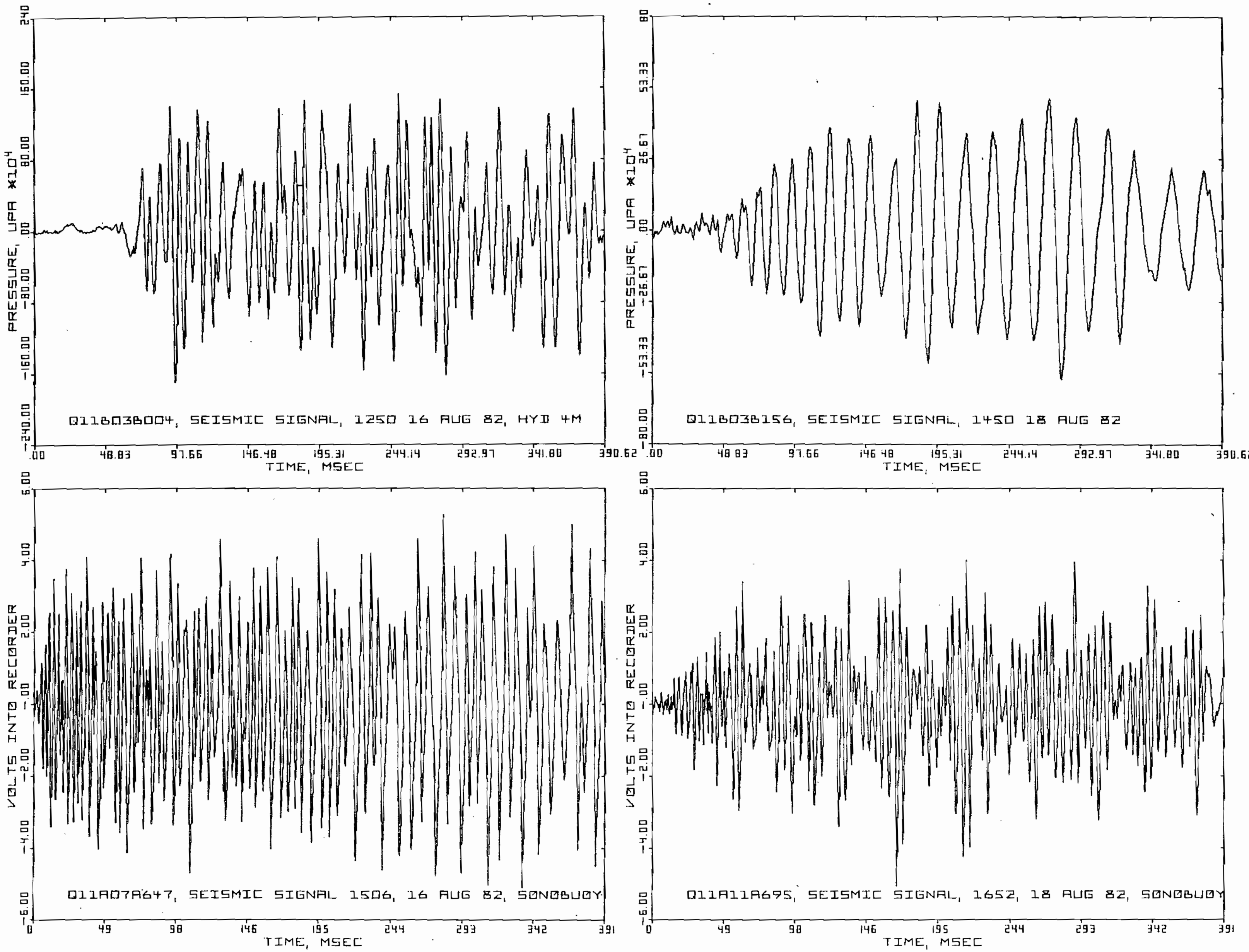


FIGURE 12. Waveforms of four seismic signals received 52-75 km from 'GSI Mariner'. The upper two signals were received via a hydrophone; the lower two via sonobuoys.

'Edward O. Vetter'

We recorded seismic signals from the vessel 'Edward O. Vetter' on 5 August 1981. This vessel was using an airgun array with total gun volume about 2000 cu in, or 33 L (J. Stone and K. Bottomly, GSI, pers. comm. to W.J.R.). The sonobuoy was about 50 km from the ship. These sounds have not been reported before, and are of interest because bowhead whales were seen near the sonobuoy (Richardson et al. 1983c). The sonobuoy was an AN/SSQ-41B that had been modified so its hydrophone deployed to a depth of only 9 m. The waveform and spectrum are shown in Figure 13. The waveform graph shows that the predominant frequencies were higher for the early-arriving than for the later-arriving part of the pulse, as is typical at long range. The received level was 117 dB//1 µPa.

Carl Savit of Western Geophysical has pointed out the potential importance of aspect in considering the frequencies received from a geophysical survey vessel. (Aspect is the angle between the survey ship's heading and the line from the survey ship to the receiver.) From the point of view of the geophysical survey, energy at frequencies above 125 Hz is largely lost through absorption in the bottom, and therefore does not figure importantly in the echoes from sub-bottom layers. Thus, survey sources are designed to concentrate energy at lower frequencies. Arrays of these sources focus energy downward. However, a receiver in the horizontal plane may detect higher frequency components, partly because of differences in the time of arrival of energy from the different guns or other elements in the array. The time differences in the arrival of the individual source signals may be very short, corresponding to frequencies much higher than 125 Hz. Thus, even small changes in aspect of the source vessel may result in marked changes in waveforms and spectral energy content for the received signals.

Tarsiut Artificial Island

Tarsiut is a caisson-retained artificial island in 23 m of water off the Mackenzie Delta (Fig. 1). The caissons are constructed of concrete, and the interior of the island is dredged material. Two wells were drilled from Tarsiut between late 1981 and early August of 1982.

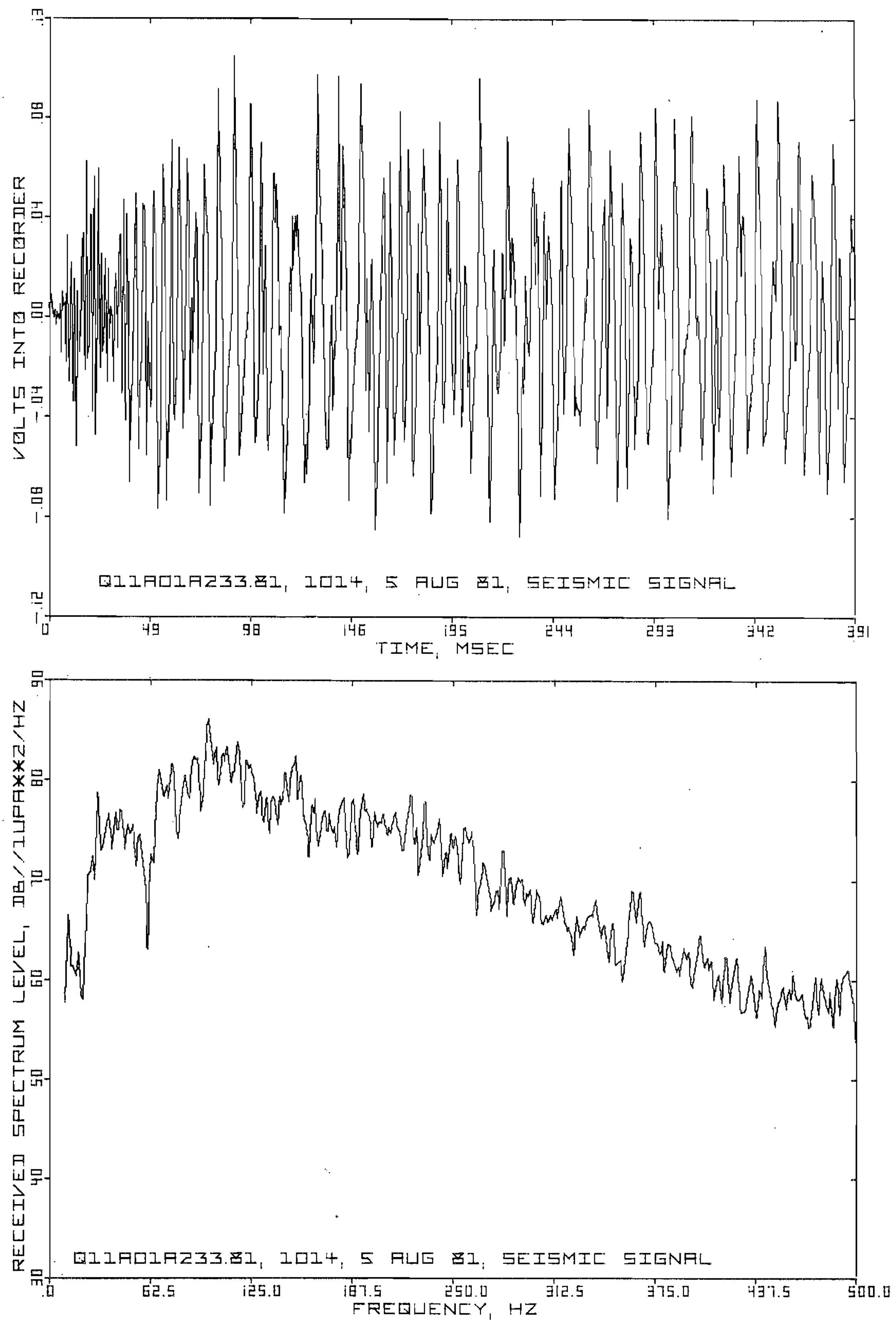


FIGURE 13. Waveform and spectrum for a seismic signal received about 50 km from 'Edward O. Vetter'. The signal was received via a sonobuoy on 5 August 1981. Received spectrum levels are meaningful in a relative but not an absolute sense.

'Sequel' travelled to Tarsiut Island twice during August 1982, but drilling had been completed before our first visit on 6 August. Figure 14 presents two pairs of spectra, one for 01:00 MDT on 7 August, when some industrial source was contributing strong noises to the water, and the second for 08:40 on the same day. There were always several tugs, supply ships, and barges at Tarsiut. Our range from Tarsiut itself was 1.1 km (0.6 n.mi.) at both times, but the other vessels were at various ranges from 1.1 to 5.3 km. The noises for 01:00 MDT were the most intense we recorded at Tarsiut. Water depth was 21 m. The band level for 10-500 Hz was 133.3 dB and the strong tones were at 26 Hz (98 dB), 55 Hz (113 dB), 115 Hz (116 dB), and 132 Hz (119 dB). Levels at frequencies from 1000 Hz to at least 8000 Hz were also unusually high (cf. Fig. 3-6). The band level for the quieter recording at 08:40 was 126.1 dB//1 µPa in the 10-500 Hz band. Tones at 56 Hz (110 dB) and 251 Hz (110 dB) are especially strong. The small family of tones including 56 Hz has a 5 Hz spacing. Levels at frequencies above 1000 Hz were not elevated nearly as much as during the earlier recording.

The second visit by 'Sequel' was at mid-day on 15 August. Pile driving was occurring on the southeast side of the island during our recording 0.46 km (0.25 n.mi.) WNW of the island, but we never heard sounds suggesting pile driving. The technique in use involved a vibrator, and the operator said it was silent. Other vessels were in the vicinity, and the support vessel 'Norweda' was approaching the island from the east at a range of about 3.7 km. Figure 15 presents spectra for this period. The 10-500 Hz band level was 118.6 dB, and the levels of the peaks at 91 and 121 Hz were 104 and 112 dB//1 µPa respectively.

For comparison, Figure 6 in the ambient noise section shows the noise spectrum 18.5 km (10 n.mi.) west of Tarsiut about 3 h later. Levels were markedly lower than those shown in Figure 15 at all frequencies up to 8000 Hz. The 10-500 Hz band level 18.5 km from Tarsiut was 103.5 dB, or 15 dB lower than 0.46 km from Tarsiut.

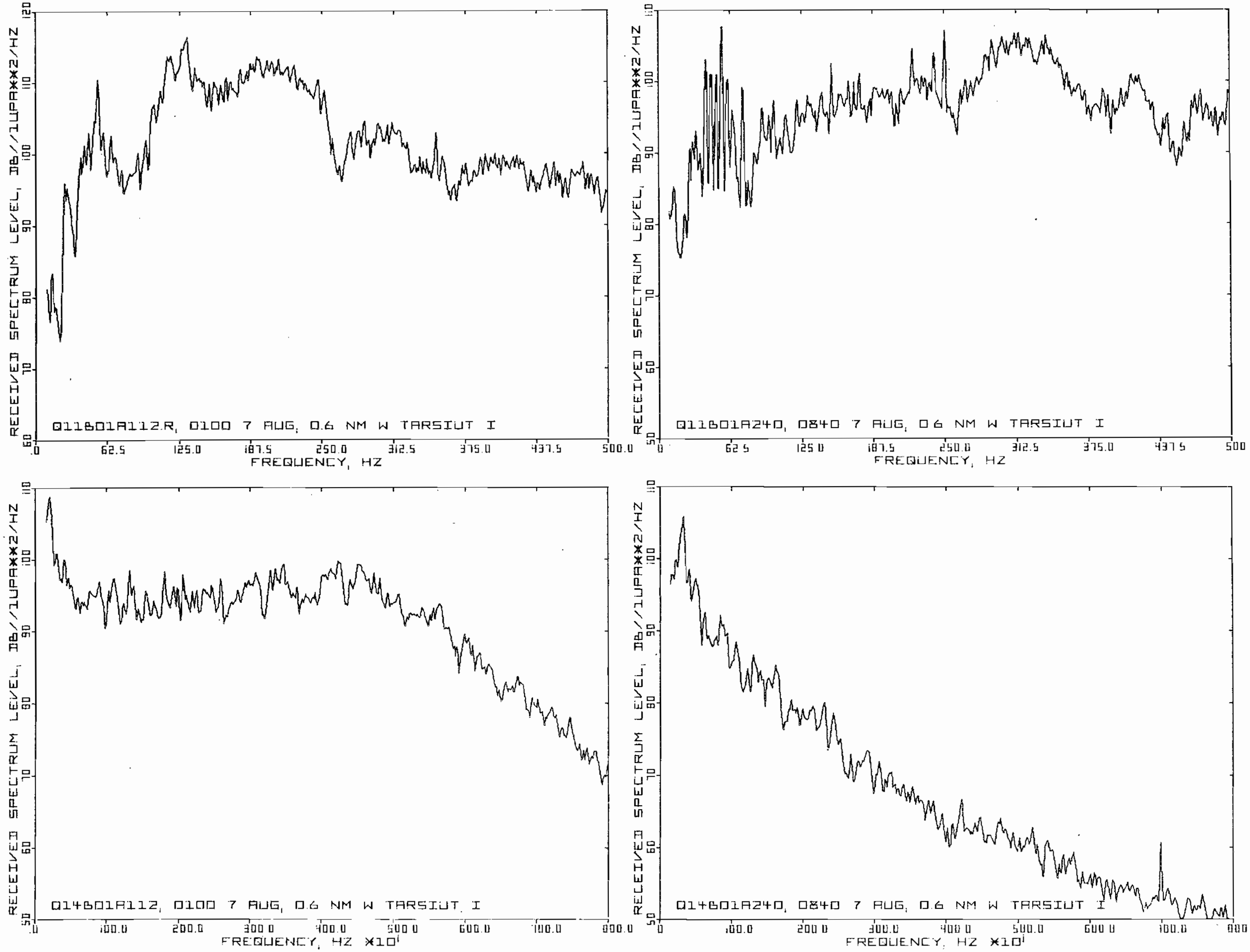


FIGURE 14. Spectra for noise near Tarsiut Island at two times on 7 August 1982. The range from Tarsiut was 1.1 km (0.6 n.mi.), but several vessels were nearby. Spectra for frequencies up to 500

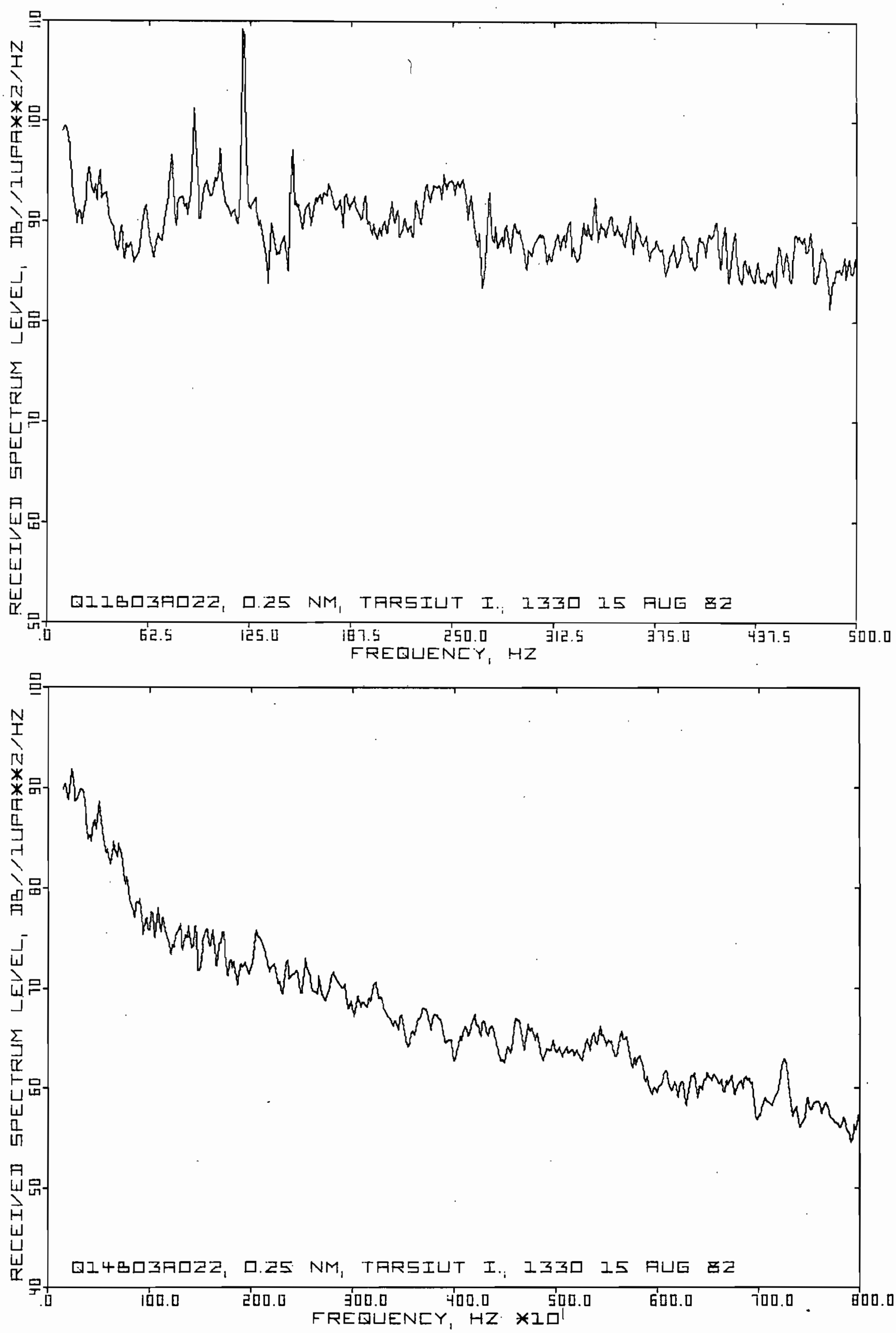


FIGURE 15. Spectra for noise near Tarsiut Island on 15 August 1982. The range from Tarsiut was 0.46 km (0.25 n.mi.), but several other vessels were nearby.

Drillships

Detailed information about drillship noise was obtained in 1981 (Greene 1982), and only limited additional information was collected in 1982. Throughout August 1982, the drillship 'Explorer I' was operating at a site about 18 km east of Tarsiut Island in water 17 m deep. 'Explorer I' was 'logging' on 10 August when we recorded sounds near her. There were other vessels around, most notably the hopper dredge 'Gateway' underway at ranges between 1.4 and 6.5 km. Extraneous sounds made recordings at longer ranges difficult to interpret, but in Figure 16 we present spectra of noise received 170 m (0.09 n.mi.) from the starboard beam. Figure 17 presents corresponding spectra for range 610 m (0.33 n.mi). For the 0.09 n.mi. range, the 10-500 Hz band level was 124.9 dB. Strong tones occurred at 88 Hz (112 dB), 211 Hz (118 dB), 354 Hz (107 dB), and 501 Hz (108 dB). For a range of 0.33 n.mi., the 10-500 Hz band level was 112.9 dB and the strongest tone was at 88 Hz (103 dB).

Figure 3, presented earlier as an example of ambient noise, represents sounds recorded 11 km from the drillship 'Explorer III' while it was drilling. There was little evidence of drillship noise at either this range or at another sonobuoy dropped 18.5 km from 'Explorer III' earlier that same day. The received levels in the 10-500 Hz band were 99.5-100.7 dB//1 µPa at 11 km and 100.5 dB at 18.5 km. Levels in the 10-1000 Hz band were very similar: 100-101 dB at 11 km and 101 dB at 18.5 km. No pronounced tones were detected at either range.

Dredges

In 1980 and 1981 we obtained recordings of sounds from the suction dredge 'Beaver MacKenzie' and from the hopper dredge 'Geopotes X' underway and loaded. We have since learned that a damaged propeller was found on 'Geopotes X' during her spring readiness inspection for 1982, and perhaps the high noise levels observed in 1981 were the result of that (J.G. Ward, Dome Petroleum, pers. comm). In 1982 we recorded sounds from hopper dredges

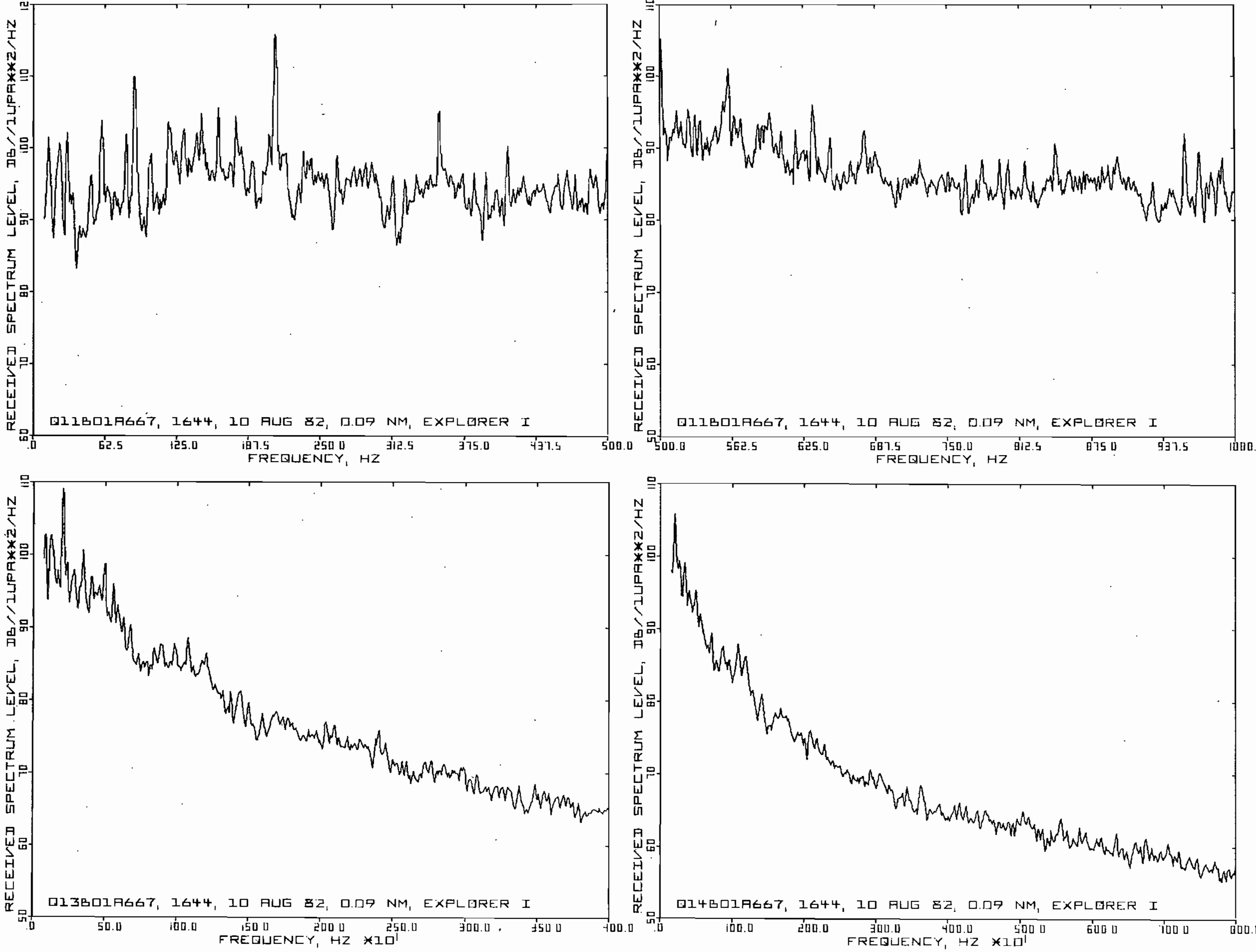
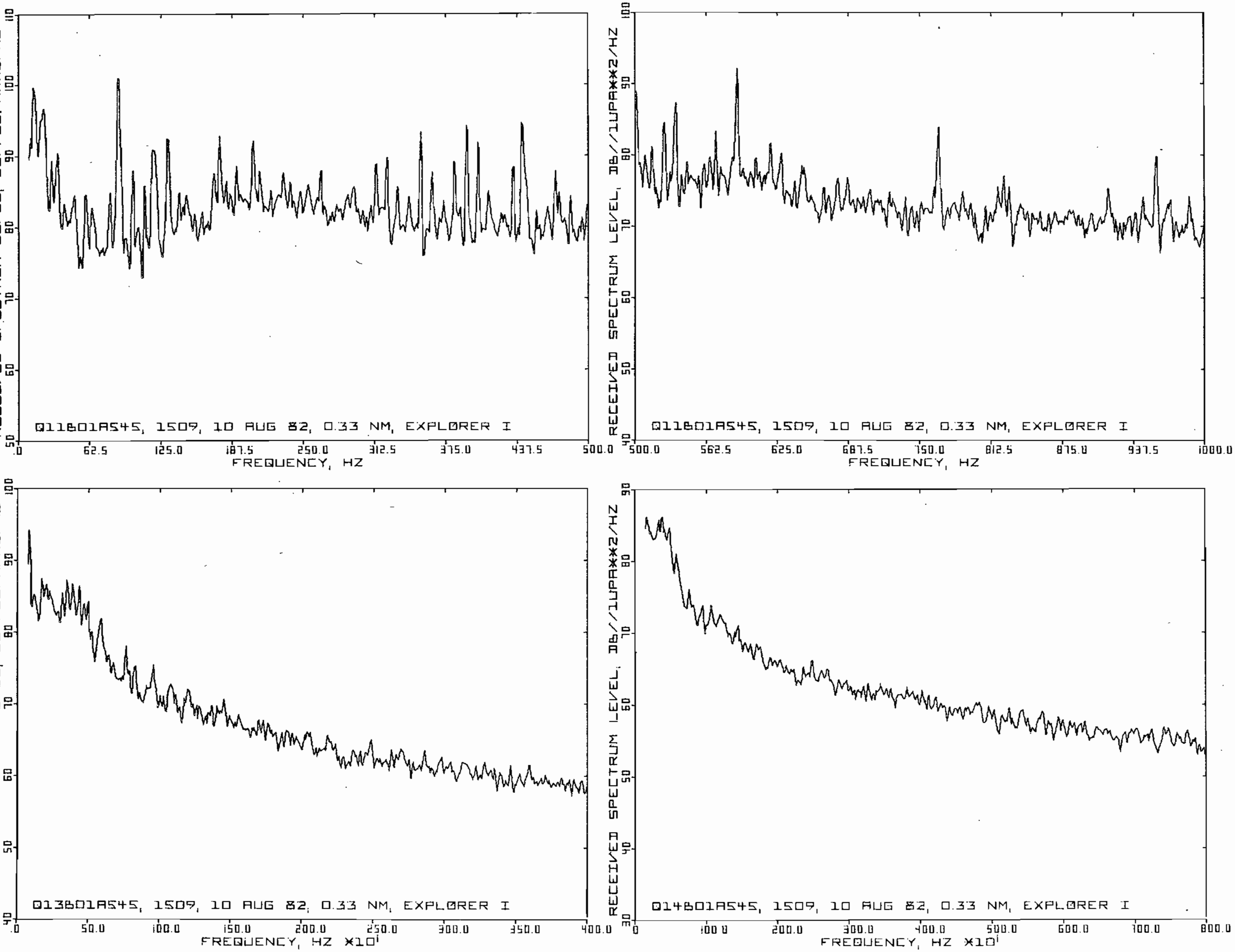


FIGURE 16. Spectra for noise from drillship 'Explorer I' while logging. The range was 170 m (0.09 n.mi.).



URE 17. Spectra for noise from drillship 'Explorer I' while logging. The range was 610 m (0.33 n.mi.)

Figure 18 presents spectra for the hopper dredge 'Gateway' underway empty at a range of 1.06 km (0.57 n.mi.) on 11 Aug. The 10-500 Hz band level was 129.2 dB and the level of the strongest tone, at 209 Hz, was 120 dB. Shortly before, 'Gateway' had been dumping her load at the Kadluk island construction site in 12 m of water (Fig. 1). Kadluk is 10.2 km from 'Explorer I' and 15.3 km from Tarsiut Island. The corresponding spectra appear on the left side of Figure 19. At the 1.5 km (0.8 n.mi.) range, the band level from 10-500 Hz was 129.4 dB. The 209 Hz tone was less prominent during the dumping phase. While dumping, 'Gateway' travelled ahead very slowly if at all. A short time later, when the dumping appeared to have stopped, the spectra were as shown in the right half of Figure 19; the 10-500 Hz band level had decreased to 119.7 dB. The range at this time had decreased only slightly. During the dumping period the support vessel 'Arctic Ublereak' was alongside 'Gateway' to provide accurate position fixes to assure that the dredge load was dropped at the desired location.

Figure 20 contains spectra for 'Geopotes X' picking up a load at a range of 0.43 km (0.23 n.mi.). The 10-500 Hz band level was 141.4 dB. Compared to the spectrum of the same ship underway in 1981 at similar range, 0.46 km (Greene 1982, p. 297), the peak level at about 80 Hz is 6 dB lower here. However, the level of the tone at about 400 Hz is 8 dB higher in 1982. We did not compute band levels in analyzing 'Geopotes X' signals in 1981, but it appears from comparing spectra that the 'underway loaded' condition is slightly noisier than the dredging condition.

To facilitate comparison of dredge sounds, we have converted the received levels in the 10-500 Hz band to the expected levels at a range of 1 km (Table 3). This conversion assumes that propagation is cylindrical, (10 log R), with an additional linear absorption term of 1.5 (R). The exact coefficients are not critical because all of the sounds compared were recorded at a rather narrow range of distances, 0.43-1.5 km. It appears that 'Gateway' produced similar noise levels while dumping and travelling empty. In comparison to these values, 'Geopotes X' engaged in dredging produced somewhat more noise, and she probably produced even more noise when travelling.

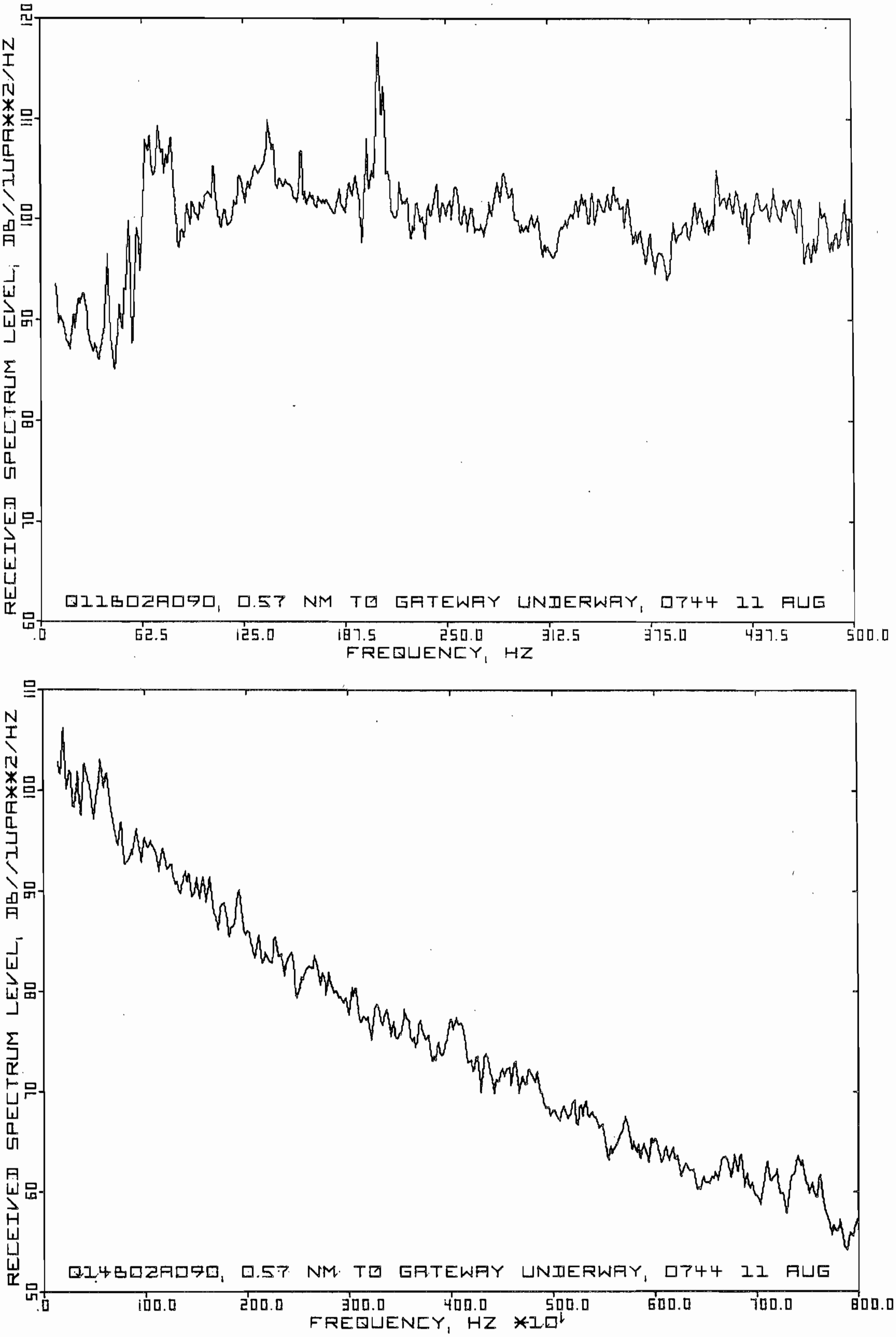


FIGURE 18. Noise spectra for hopper dredge 'Gateway' underway empty at a range of 1.06 km (0.57 n.mi.)

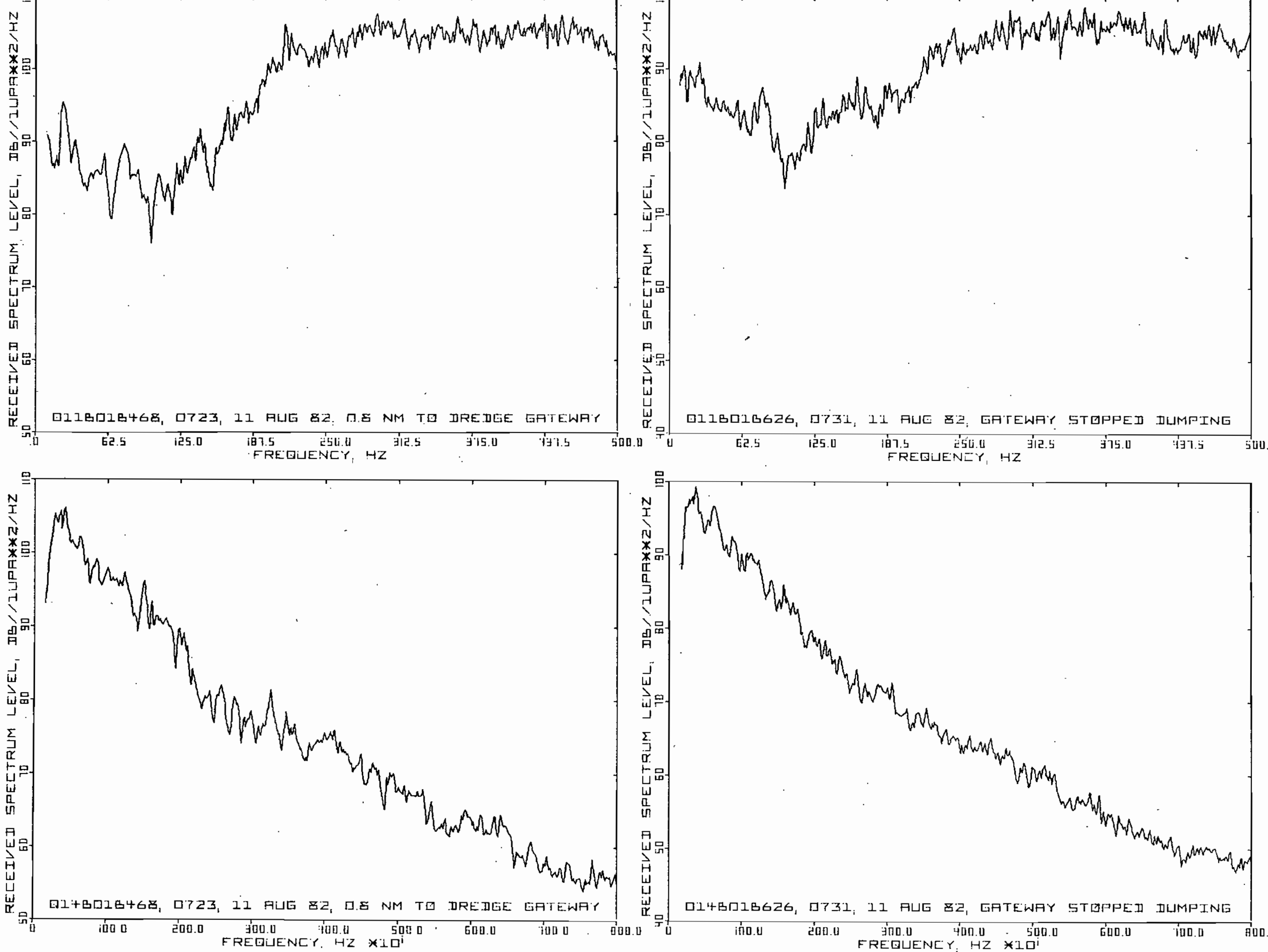
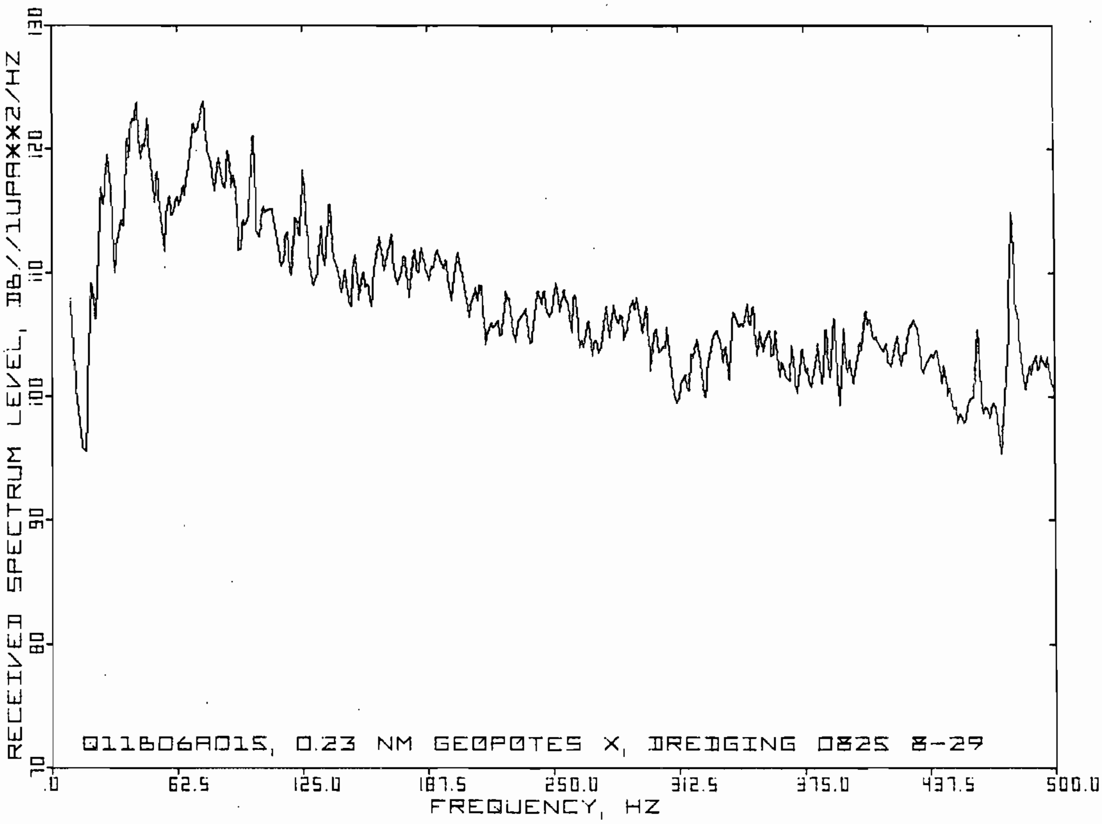


FIGURE 19. Noise spectra for hopper dredge 'Gateway' dumping her load at a range of 1.5 km (0.8 n.mi.).



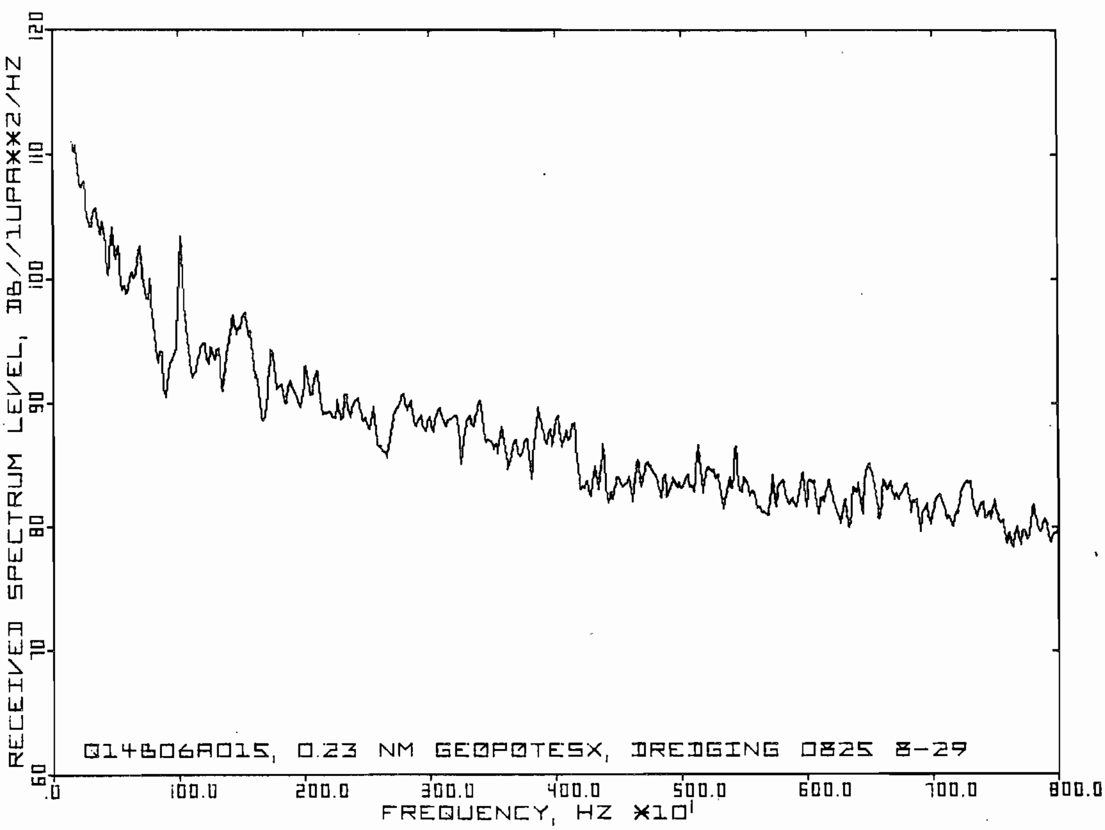


FIGURE 20. Noise spectra for hopper dredge 'Geopotes X' picking up a load at a range of 0.43 km (0.23 n.mi.).

Table 3. Noise levels in the 10-500 Hz band from the hopper dredges 'Gateway' and 'Geopotes X', August 1982.

	Range of Recording (km)	Band level, 10-500 Hz, dB//1 µPa	
		As Received	Estimated for Range 1 km*
'Gateway' underway empty	1.06	129.2	130
'Gateway' dumping	1.5	129.4	132
'Gateway', end of dumping	1.5	119.7	122
'Geopotes X', dredging	0.43	141.4	137

* Assuming that propagation losses are 10 log(R) + 1.5(R).

Boats

Aside from the measurements of dredge and drillship noise reported above, the MV 'Sequel' was the only vessel whose noise was studied in 1982. 'Sequel' is the 12.5-m diesel-powered fishing boat used in support of our work in 1981 and 1982. See Greene (1982, p. 283) for additional information about this vessel.

Figure 21 shows spectra for noise from 'Sequel' as she approached a sonobuoy at range approximately 100 m and speed 8 km/h on 16 August 1982. The 10-500 Hz band level was 107.5 dB//1 µPa. The level of the tone at 33 Hz was 101.7 dB, and the level for the tone at 955 Hz was 89.4 dB.

Noise from 'Sequel' was also recorded as she moved away from the sonobuoy at 13 km/h during a boat disturbance experiment on 16 August 1982. The overall level in the 10-500 Hz band was 103 dB//1 µPa when 'Sequel' was about 2 km away.

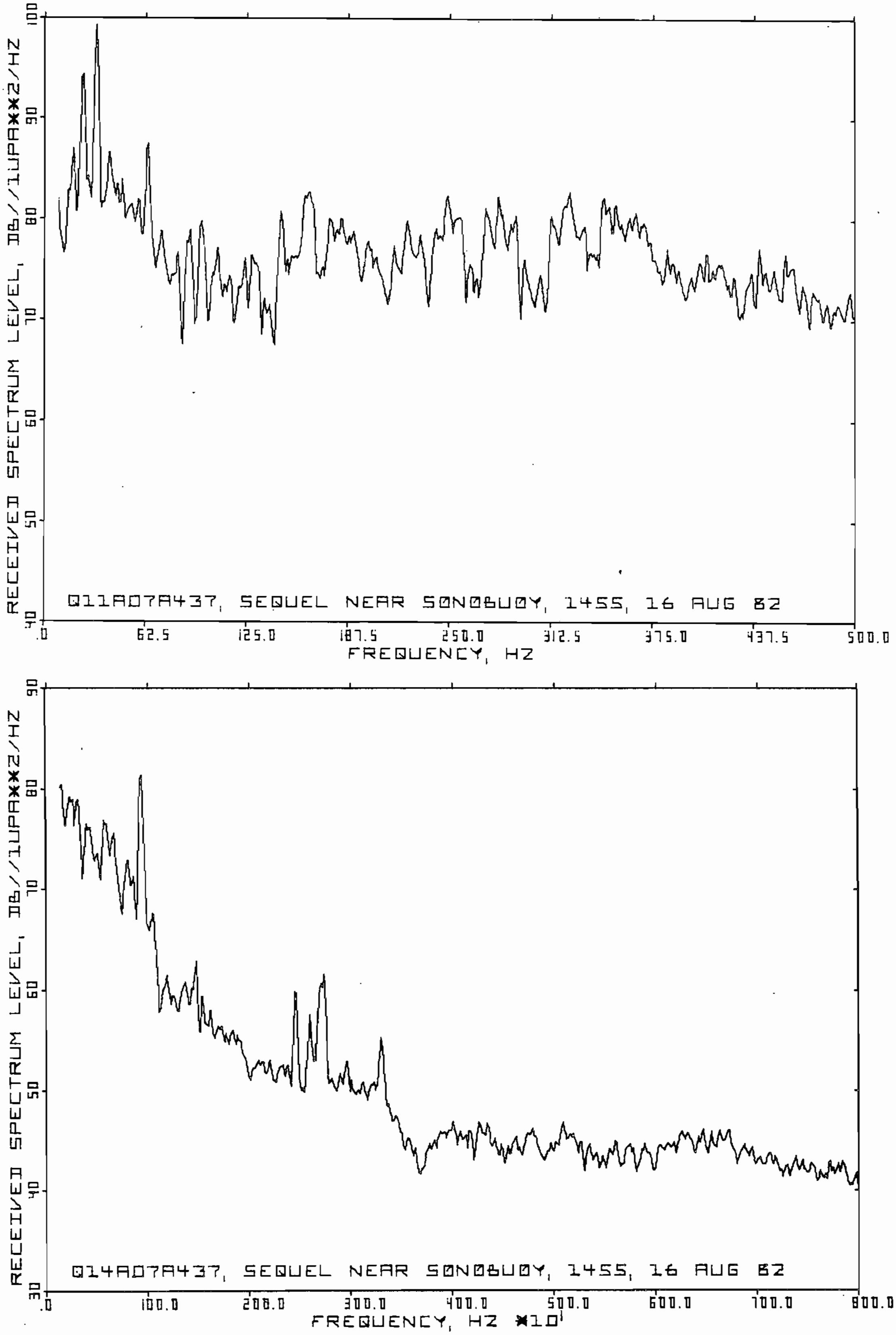


FIGURE 21. Spectrum of 'Sequel' underway near a sonobuoy.

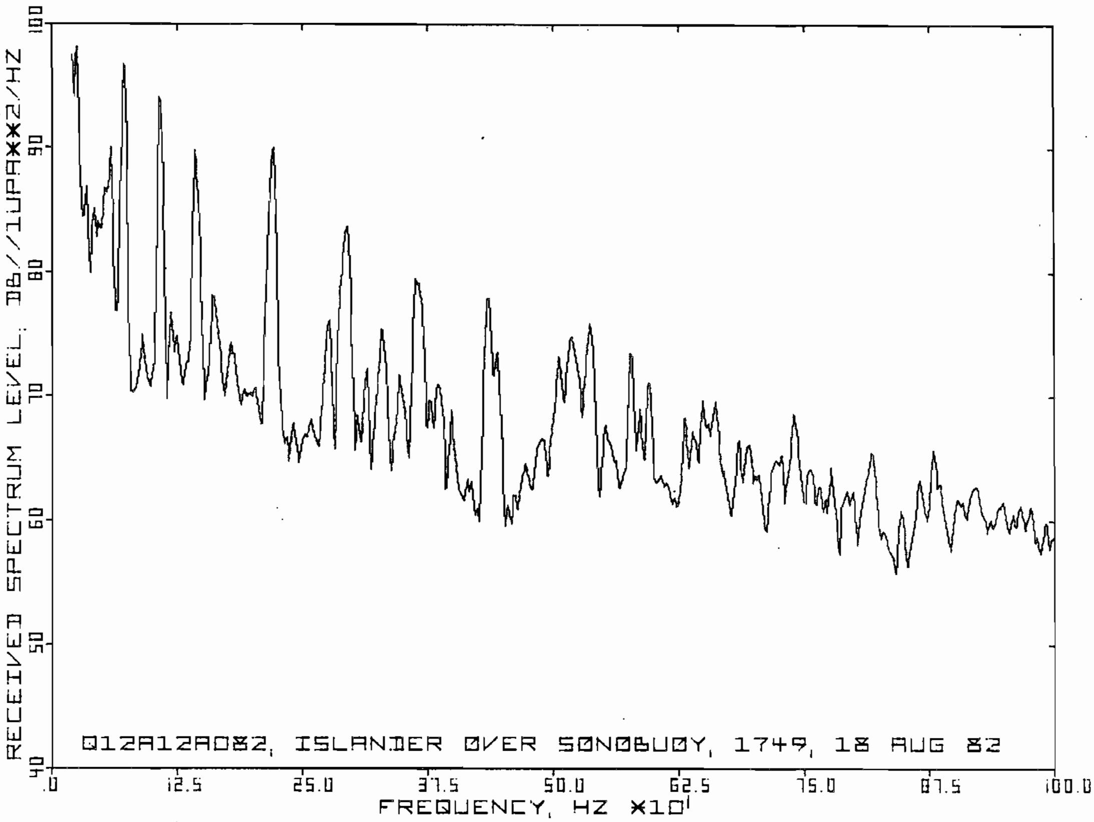
Aircraft

We did not obtain additional sound measurement data from aircraft flyovers at various altitudes in 1982. However, we did analyze the sonobuoy signals recorded on several occasions when the observation aircraft, the same B-N Islander used in 1980-81, flew over the buoy. Figure 22 presents spectra for one instance when the Islander flew over at 457 m (1500 ft) a.s.l. The band level for 20-2000 Hz was 110.3 dB. The spectrum for the 20-1000 Hz band looks very similar to the spectrum for a previous measurement of noise from the same aircraft in 1980 (Greene 1982, p. 303A). However, the 1980 spectrum was based on an 8 s portion of a flyover at 305 m a.s.l., whereas the top graph in Figure 22 is based on a 4 s portion of a flyover at 457 m. For Figure 22, water depth was about 300 m; sea state was Bf1.

Sounds During Playback Experiments

Three playback experiments involved transmitting drillship sounds underwater in the presence of bowhead whales. Only in the test of 18 August did we achieve the full output level of the J-11 projector. The spectra in Figure 23 were computed from the sonobuoy signals received about 2 km from the projector on that date. The measured source level at the J-11 was 164 dB//1 µPa-m, and the 10-500 Hz band level received 2 km away at the sonobuoy was 109.2 dB. The received level of the 275 Hz tone was 103 dB. Based on our received level vs. range data for drillship noise (Greene 1982, p. 326), 103 dB is the expected received level for this tone at a range of 7 km. Thus, the source level of the projector while broadcasting drillship sound (164 dB) was apparently less than that of the actual drillship. This assumes that propagation conditions were the same as those in 1981 when the drillship signals were recorded. Actually, conditions should have been somewhat better at the site of the 1982 tests because of the deeper water.

The shape of the spectrum as received 2 km from the projector (Fig. 23) compares well with the spectrum of the taped sounds being broadcast. The latter is shown in Greene (1982, p. 323). The finer detail evident in Fig. 23 is attributable to a difference in resolution; it was 3.4 Hz in Greene (1982, p. 323) and 1.7 Hz in Figure 23 here.



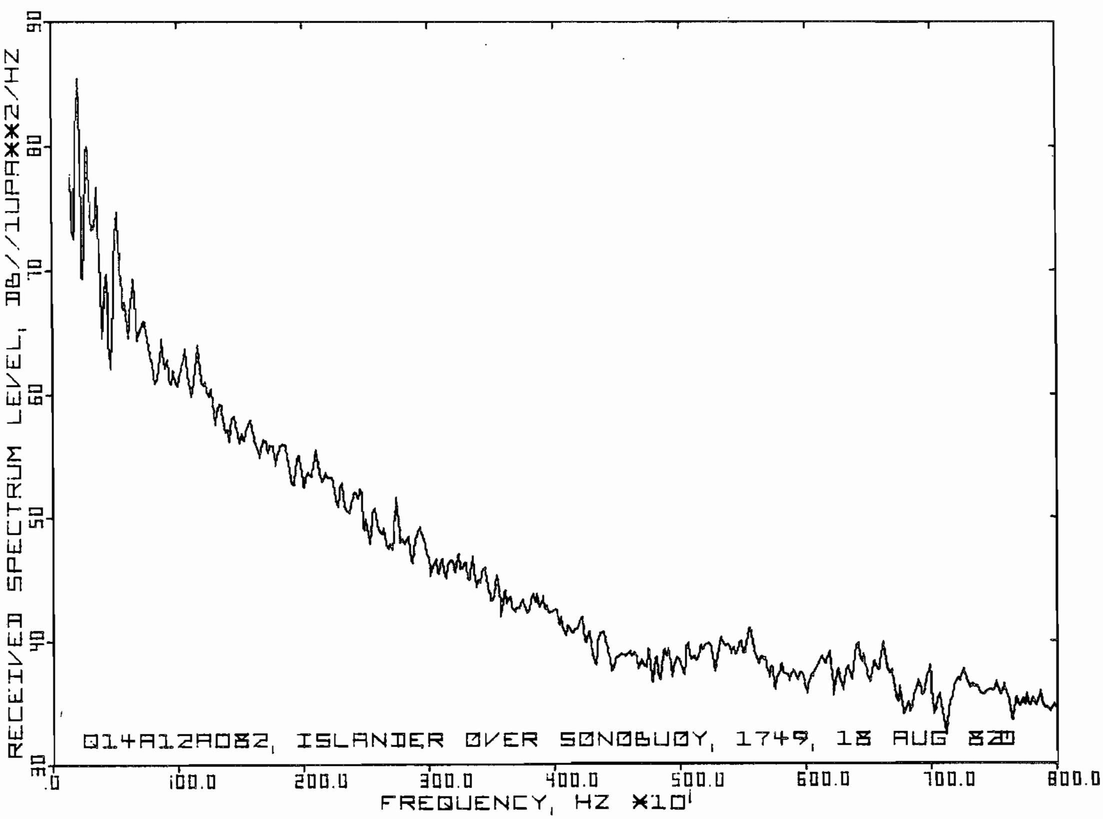


FIGURE 22. Spectra for Britten-Norman Islander aircraft flying over a sonobuoy at 457 m a.s.l. The upper spectrum is based on 4 s of

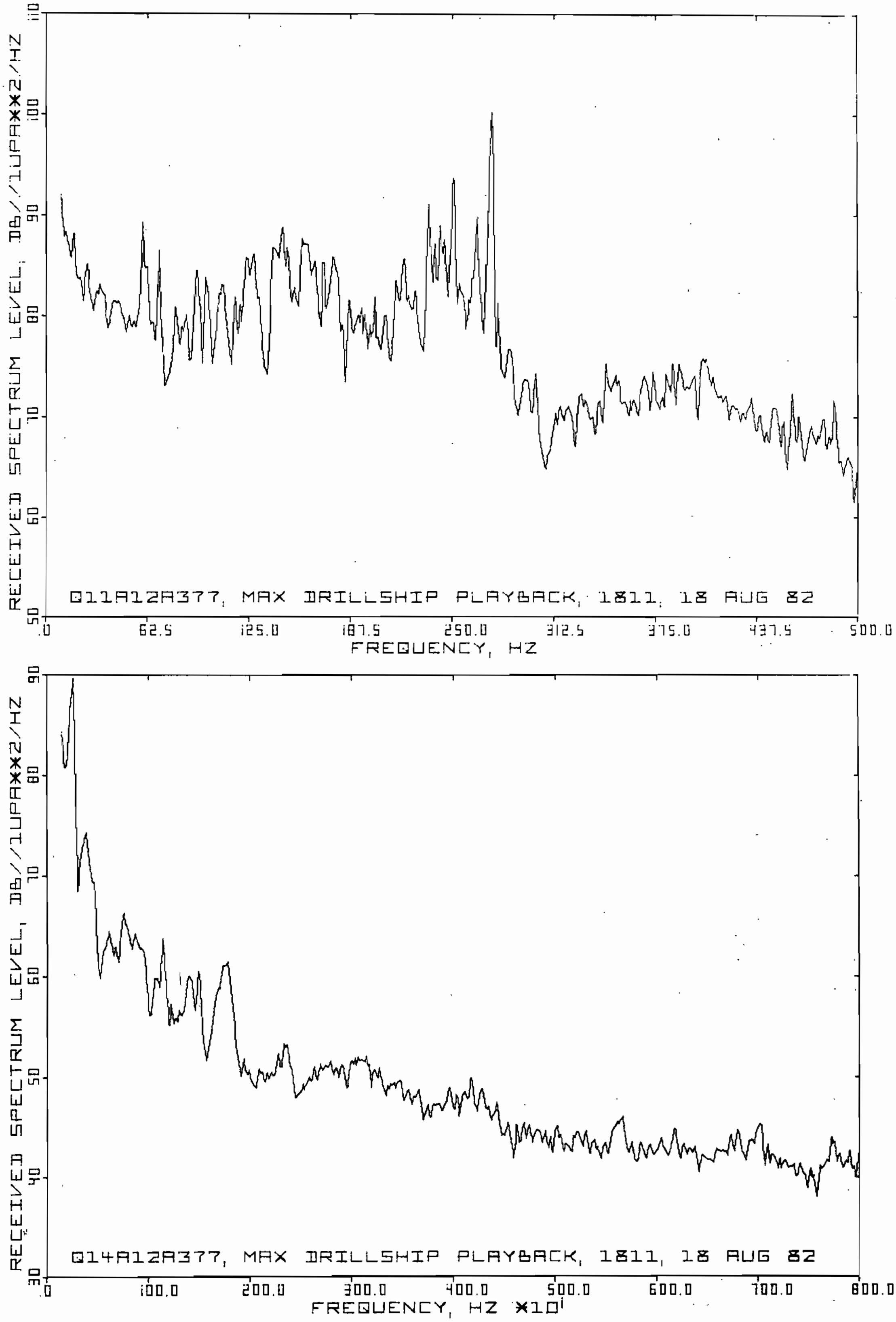


FIGURE 23. Spectra for the drillship sound transmitted at maximum level during a playback experiment. The signal was received at a sonobuoy about 2 km from the projector.

The other two playback experiments were conducted in the same general area on 16 and 19 August 1982. Richardson et al. (1983c) describe the circumstances. That section of the report also gives further information about projector source level, received level at range 1.5-2 km, and ambient noise level before and after each playback.

DISCUSSION

The 1982 effort has led to an extension of the results from the 1980-81 efforts. We recorded seismic survey signals from ranges of 0.9-14.8 km, compared to 8-29 km previously. We recorded sounds from an artificial island (Tarsiut) and from hopper dredges dumping and dredging loads. Also for the first time, we projected previously recorded sounds (of a drillship) in playback experiments to observe bowhead behavioral responses. Our recording and analysis methods were basically the same as used in the 1981 effort. One important change was the use of an additional hydrophone in the boat system--a low frequency hydrophone with especially low self noise for use at frequencies up to 1000 Hz. Another change was an increase in the spectrum analysis resolution for the frequency bands from 10-500 and 500-1000 Hz. Resolution in 1982 was 1.7 Hz, as compared with the 3.4 Hz used previously. In addition, broadband levels for 10-500 Hz and certain other bands were calculated in 1982 for the first time in the project. These changes were enhancements and did not detract from our ability to compare results from the different years.

The short range seismic signals came from 'Arctic Surveyor', the same survey ship measured in 1981. In 1982, however, she was operating in shallower water (9 m vs. 25-50 m in 1981) and was using open-bottom gas guns rather than sleeve exploders. The new sources were expected to yield 50% more source level, but we do not have specific information about the source level of either the sleeve exploders or the gas guns.

The 1982 results showed that low frequency energy (below 100 Hz) predominated at ranges from 0.9 to 1.9 km, was about equal with higher frequency energy at 3.7 km, and that frequencies from 170 to 400 Hz predominated at 7.4 and 14.8 km, the longest ranges for which data were available. In fact, at 14.8 km the lowest frequency with dominant energy was 240 Hz.

As noted earlier, our results may have been confounded by the presence of an important geological discontinuity separating the ranges up to and including 3.7 km from the 7.4 and 14.8 km ranges. The signals from 1.9 and 3.7 km showed a precursor of low frequency energy arriving in advance of the higher frequency energy; we attribute this to a sub-bottom path with a higher velocity than the water path. The water path, being shallow, is expected to attenuate low frequencies rapidly with increasing range. Based on the measurements from 1.9 and 3.7 km, one would expect the low frequency precursor at 7.4 and 14.8 km to arrive even further in advance of the higher frequency, waterborne energy. However, the precursor was not detected at all at 7.4 and 14.8 km. The geological discontinuity is said to run northward at about 135°W longitude, and our line of receiving stations ran northeast from 'Surveyor', crossing 135°W. The results might have been different if we had run our receiving line northwestward.

From experience, exploration geophysicists know that signal energy at frequencies above about 120 Hz is wasted in reflection surveys, and they design their sources to ensure that most of their energy is below that frequency. On the other hand, we have detected energy at higher frequencies--up to 400 Hz--and during our long range measurements before 1982 we detected little energy below 100 Hz. Our 1982 data from shorter ranges show that, at close range, the bulk of energy propagating horizontally is below 100 Hz, as expected from the design of the sources. At longer ranges, especially beyond about 7 km, the low frequency energy has been severely attenuated by the medium. The high frequency energy, which is relatively weak at the source, has not been so severely attenuated and is received at high levels with respect to the background at ranges of at least 15 km.

It is important to note that the 1982 seismic survey signals discussed above were recorded in water only 9-11 m deep while the 1981 signals came from water 25-50 m deep. For the ranges that overlapped, the 1981 signals were stronger, even though the source level was supposedly greater in 1982. This illustrates the importance of water depth in determining received sound levels. It also suggests that the 'zone of noise influence' around a geophysical survey vessel may be expected to increase in radius as water depth increases.

The importance of water depth in determining zone of influence is further illustrated by our measurements of noise from the airgun array on 'GSI Mariner', which was operating in deeper water (about 100 m). On one occasion, we detected signals with level 110 dB at a range of 75 km. On another, we recorded signals with level 128 dB at a range of 54 km. In contrast, signals from 'Arctic Surveyor' in 9-11 m of water would be expected to attenuate to 110 dB at about 20 km range.

We have used the peak sound pressure levels, converted to effective rms levels, to characterize seismic survey signals at different ranges. We suspect that peak pressure is a reasonable parameter to study when considering the influence of an impulsive sound on bowheads. The frequency distribution of the signals is also important and we have presented signal spectra to show the relative concentrations of energy versus frequency for each range. Other investigators are studying seismic survey signals in connection with studies of marine mammal behavior and, for comparability of results, it will be important to agree on standardized measurement procedures.

In the case of the sounds from the Tarsiut artificial island, the significant observation is that a wide variety of sounds and sound levels can be expected. There was always an assortment of vessels around the island, and it was not possible to separate vessel sounds from island sounds. Speculatively, it seems possible that the dominant waterborne sounds came from vessels and not the island.

It should be noted that our recordings at Tarsiut were obtained after drilling had ended. There are no known recordings of drilling sounds from islands in open water.

The hopper dredge 'Geopotes X' dredging up a load made sounds comparable in level to those observed while the same vessel was underway loaded. Similarly, the hopper dredge 'Gateway' dumping her load made sounds comparable in level to those observed while she was underway empty. 'Gateway' was quieter than 'Geopotes X', but both hopper dredges were noisier than the suction dredge 'Beaver MacKenzie' dredging while at anchor at an island site.

Figure 24 presents a summary graph of received levels vs. range for industrial sources measured in the Beaufort Sea during August 1981-82. The dashed lines near the top are included to show the attenuation slopes for cylindrical spreading (10 log R) and spherical spreading (20 log R). The solid lines without data points represent regression models derived from the data. Greater attenuation with increasing range can be seen for shallower water by comparing the curves for seismic signals in 1981 and 1982 (shallower water in 1982). The 1981 data for 'Geopotes X' underway loaded may have been unusually elevated because of a damaged propeller. The points plotted for 'Gateway', Tarsiut island, and 'Geopotes X' in 1982 are 10-500 Hz band levels which include tonal powers in that band; the 1981 curves for the suction dredge, drillship, and 'Geopotes X' underway are only for the strongest tone present. The variable levels near Tarsiut artificial island are illustrated by the lower (118.6 dB) 10-500 Hz level measured at 0.46 km on 15 August as compared to the range of levels (126.1-133.3 dB) measured at 1.1 km on 6 August. From Figure 24, it is obvious that seismic signals are by far the strongest sounds introduced into the Beaufort Sea by the kinds of industrial activities that we have studied.

The 'Drillship, 278 Hz' curve in Figure 24 represents Explorer II while she was drilling. The strongest tones recorded at drillship Explorer I during logging were on the order of 20 dB below the strongest tones from Explorer II during drilling at comparable ranges. The drilling noises from Explorer III at ranges of 11 and 18.5 km were below the ambient, which is consistent with the attenuation trend measured for Explorer II drilling.

Hopper dredges, capable of taking up a load from the bottom at one place and carrying it to another place for dumping, appear among the stronger sources of industrial noise as shown in Figure 24. Dredge 'Geopotes X' both underway and dredging was noisier than other vessels measured, while dredge 'Gateway' produced slightly weaker sounds underway and dumping.

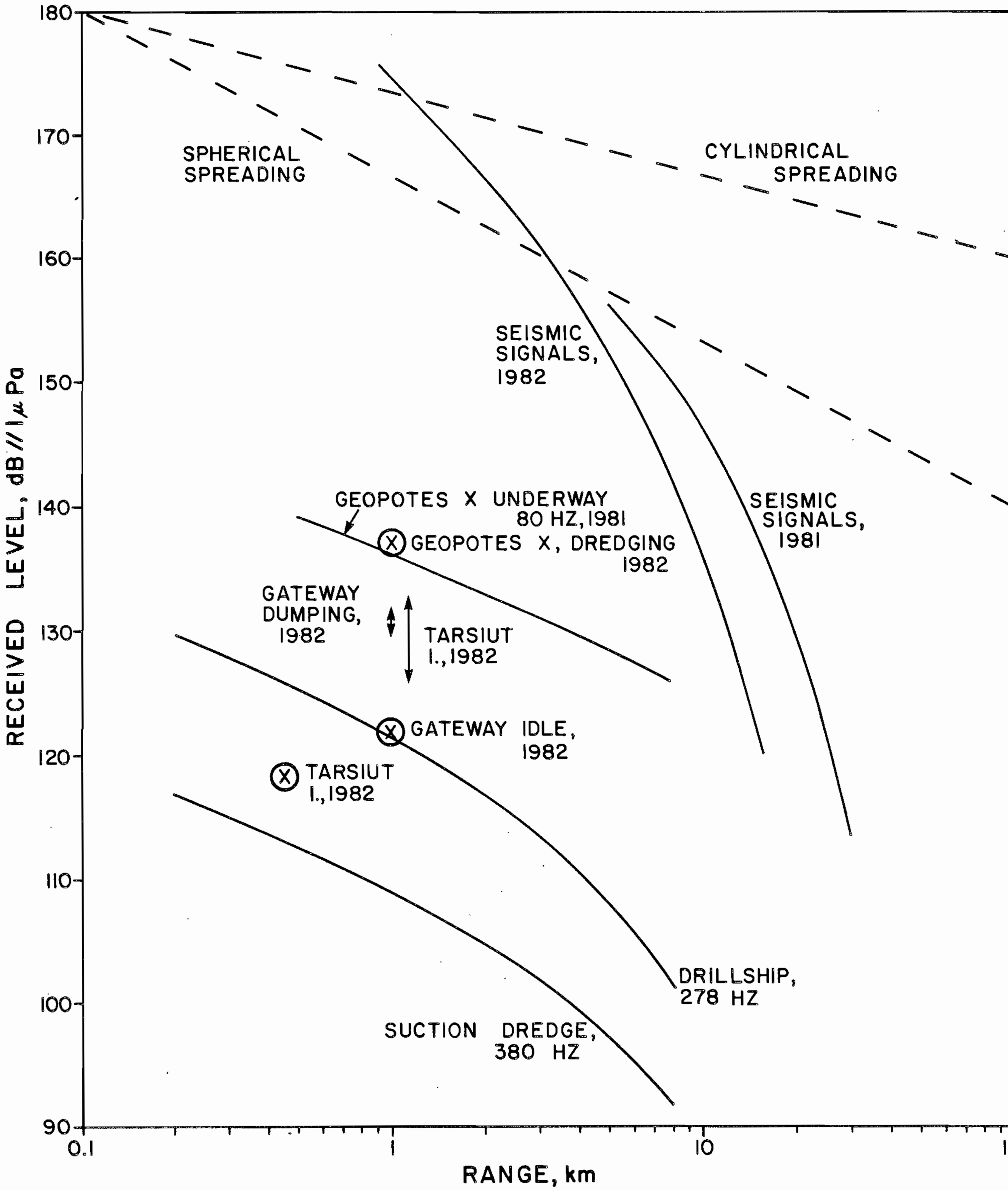


FIGURE 24. Received levels of underwater sounds from various industrial sources in relation to range, eastern Beaufort Sea, 1981-82.

Most of the energy in the various industrial sounds that we have recorded in the eastern Beaufort Sea is at frequencies below a few hundred Hertz. Most bowhead calls are also predominantly in this frequency range (Ljungblad et al. 1982; Würsig et al. 1982). Although the auditory sensitivity of bowheads has not been studied, we assume that they can detect low frequency sounds, including both their own calls and various industrial sounds. The possible effects of industrial noise on bowheads include both disturbance and masking of other sounds (e.g., masking of calls from distant bowheads). These possibilities, and the potential consequences, are discussed in the 'Disturbance' section of this report (Richardson et al. 1983c) and, more comprehensively, in Richardson et al. (1983b).

ACKNOWLEDGMENTS

Mike Zika of PRL helped prepare and check out the equipment needed for the field trip. Kerry Finley of LGL operated the sonobuoy signal receiving and recording equipment on the airplane. Peter Thomas of LGL and Len Pearson of Beaufort Environmental Support Services and skipper of 'Sequel', were very helpful and fine sailing companions on the boat. Danielle Roy, PRL, ran the computer to analyze the data. Anonymous help, but indispensible, came from Dome's radio operators at Tuk Base and on the vessels at sea, especially the drillships. Geophysical Service Inc. provided much information about the operations of their seismic vessels, and Dome, Esso and Gulf all were helpful in providing information of various types. John Richardson, project director, did an outstanding job providing support from shore and keeping our efforts directed at acquiring the most useful data. His editing of this report has enhanced its readability considerably.

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DISTRIBUTION OF BOWHEADS AND INDUSTRIAL ACTIVITY, 1980-82*

By

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ABSTRACT

A preceding section on 'Disturbance Responses of Bowheads' examined short-term behavioral responses of summering bowheads to activities associated with offshore oil exploration. However, the behavioral approach cannot determine whether these activities result in long-term displacement. This section reviews the distribution of bowheads summering in the eastern Beaufort Sea in recent years and discusses whether there have been any distributional changes attributable to oil exploration.

Methods. -- Detailed data on bowhead distribution in most of the Canadian Beaufort Sea have been collected only since 1980, and only from late July or early August to mid September. Sightings during the various studies conducted within this period are compiled here onto a series of maps, one or two per 10-d period. Survey routes are also shown on these maps. Previously unreported distributional data from this and other LGL studies in 1980-82 are included, along with results compiled from all available reports by ourselves and others.

Industrial activities are also mapped. For each 10-d period, we include one map showing the sites of offshore drilling, dredging, etc., along with the approximate number of boat trips along each route. Another map for each 10-d period shows seismic lines shot during the period, plus locations of low-energy sounding. A third type of map shows helicopter traffic and ice conditions during the 1-10 and 22-31 August periods. 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 support traffic via boat and helicopter.

In **1980**, bowheads were more numerous close to shore than in the subsequent two years. Around 2 August, many moved into shallow waters off the central Mackenzie Delta, the main industrial area. Some were within 5 km from the island construction operation at Issungnak. Whales were scarce farther east off the Tuktoyaktuk (Tuk) Peninsula in early August, but moved into that area of lesser industrial activity in mid August. By late August, very large numbers were widely distributed off the Tuk Peninsula, many in

water <20 m deep. Numbers off the Delta were somewhat reduced, but still high. Previous to late August, there was no survey coverage west of the Delta; in late August at least a few whales were present north of Herschel Island. In early September, fewer whales were found off the Tuk Peninsula, and they were farther offshore. Numbers off the Delta were much reduced, but whales were seen regularly near Herschel Island. Bowheads were first seen in Alaskan waters on 4 September.

In **1981**, survey coverage was more comprehensive and most bowheads remained farther offshore. In late July, most were either far offshore in pack ice or in Amundsen Gulf. In early August many moved south onto the outer continental shelf off the Mackenzie Delta, with lesser numbers off the Tuk Peninsula. None were seen near Issungnak where whales were abundant in early August 1980. In mid August the whales were more evenly distributed from Herschel Island to Cape Bathurst, mainly in waters >50 m deep, but there was a concentration in shallower water off the central Delta. Some of the latter animals were <10 km from an artificial island and drillship. In early September, most bowheads were still in Canadian waters, with many off the Tuk Peninsula and Herschel Island and lower densities elsewhere. The first sighting in Alaskan waters was on 7 September.

In **1982**, most bowheads were far enough offshore or west to be outside the main industrial area. In early August, the only sightings in the Canadian Beaufort Sea were on the outer shelf off the western Delta and Yukon, and many were moving west. Some bowheads were seen in the Alaskan Beaufort as early as early August. In mid August, there was a major concentration near Herschel Island, with low densities off the Delta and Tuk Peninsula. In late August, many bowheads remained off Herschel Island; others were along the shelf break off the western Delta and on the outer shelf off the eastern Tuk Peninsula. In early September, many were still near Herschel Island, with a few on the outer shelf off the Delta and Tuk Peninsula.

Discussion. -- Most of the Canadian Beaufort Sea was not surveyed for bowheads before 1980. However, a longer series of data is available for the area of most intense industrial activity off the eastern Mackenzie Delta.

Island construction and traffic to drillships farther north have occurred off the Delta each summer since 1976, and seismic exploration since 1971. In 1976 and 1977, many bowheads entered shallow waters off the Delta in early August. They did not do so in 1978 or 1979. Many whales occurred off the eastern part of the Delta in 1980, but few were there in 1981 and almost none in 1982. Given the reappearance of many whales off the Delta in 1980, there is no clear trend for decreasing numbers in that small area. For other parts of the Canadian Beaufort Sea, the lack of data from years before 1980 makes it impossible to assess whether the 1981 and 1982 distributions were unusual.

In 1980, 1981 and 1982, seismic exploration occurred over much of the Canadian Beaufort Sea -- both within and beyond the main industrial area. Numerous bowheads were in areas ensonified by seismic noise in 1981 and 1982 as well as in 1980.

Whether or not industrial activities affect bowhead distribution in summer, bowhead movements probably depend strongly on the distribution and abundance of zooplankton. Factors affecting zooplankton in the eastern Beaufort Sea are poorly known, but probably include the variable volume and movement of fresh water from the Mackenzie River, and hydrographic phenomena at the shelf break and the ice edge. The variable distribution of ice probably also has direct effects on whale distribution.

INTRODUCTION

The primary focus of the study reported in this volume has been the short-term behavioral reactions of bowheads to actual and simulated industrial activities. Behavioral responses are studied primarily because a positive response provides an immediate indication that the whales may be sensitive to the industrial activity. We have studied the behavior of bowheads in the presence of boats, aircraft, seismic exploration, drillships and dredging (Fraker et al. 1982; Richardson et al. 1983b).

The long term reactions of the bowhead population to offshore industrial activity are ultimately of greater concern than are short term behavioral responses. Long term reactions might, in theory, include such interrelated factors as increased stress, reduced overall food intake during the summer feeding season, reduced reproductive success or survival rate, and displacement from parts of the traditional range. All of these medium to long term effects are difficult to detect. Even if detected it would be difficult to determine whether they were attributable to industrial activity rather than to some form of natural variation.

The one type of long term effect on bowheads that might be detectable from data now being collected is displacement from parts of the traditional range. Gray whales were apparently displaced from at least one of their wintering lagoons when ship traffic and other human activities intensified, and returned years later when ship traffic decreased (Reeves 1977). In other cases, suggested displacements of baleen whales by prolonged human activities have not been demonstrated convincingly (reviewed by Richardson et al. 1983a). These possible cases include other gray whale wintering areas and migration routes (Rice 1965; Rice and Wolman 1971; Wolfson 1977; Dohl and Guess 1979), humpback whale wintering and feeding areas (Norris and Reeves 1978; Jurasz and Jurasz 1979; MMC 1979/80), and whales in areas of heavy ship traffic off Japan (Nishiwaki and Sasao 1977). Most of these data are equivocal regarding whether whales are displaced by industrial activities. However, it is clear that they often return each year to areas where they have been hunted from ships or exposed to heavy vessel traffic.

Aerial surveys provide the type of comprehensive information about bowhead distribution that can be used in detecting changes in distribution. This technique has been used extensively to detect seasonal changes in distribution during migration around Alaska and during the summer in the Canadian Beaufort Sea. If continued over a period of years, aerial surveys could show whether long term changes in distribution had occurred.

Comprehensive aerial surveys have been done in Alaskan waters during the spring and fall migration seasons in 1979 (Ljungblad et al. 1980), 1980 (Ljungblad 1981), 1981 (Ljungblad et al. 1982) and 1982 (Ljungblad pers. comm.). The National Marine Fisheries Service conducted aerial surveys in some earlier years. These results provide valuable background data from years before there was much offshore oil exploration, aside from geophysical exploration, in the Alaskan Beaufort Sea.

In the eastern Beaufort Sea where the Western Arctic stock of bowheads spend the summer, systematic aerial surveys for bowheads did not begin until 1980. Before 1980, the only available data on summer distribution were from logbooks of commercial whalers who operated in the area at the start of this century, and incidental sightings by scientists and industry personnel engaged in offshore work (Fraker 1979; Fraker and Bockstoce 1980). These records suggested that most bowheads spend the early summer in Amundsen Gulf and the extreme eastern part of the Canadian Beaufort Sea--east of the area of offshore oil exploration (Fig. 1)--and then move westward off the Tuktoyaktuk Peninsula, Mackenzie Delta and Yukon coast in August and September.

By 1980, when systematic aerial surveys and other studies of bowheads in their summering areas began, full-scale offshore oil exploration had been underway for some years. Drilling from artificial islands in very shallow nearshore waters began in the early 1970's, and drillships began to work farther offshore in 1976. Systematic aerial surveys have continued on a larger scale in the summers of 1981 and 1982. The three summers of surveys have shown that many bowheads sometimes occur in the areas of most intense industrial activity. However, they have also shown that, at other times during the summer, bowheads are very scarce in the industrial area.

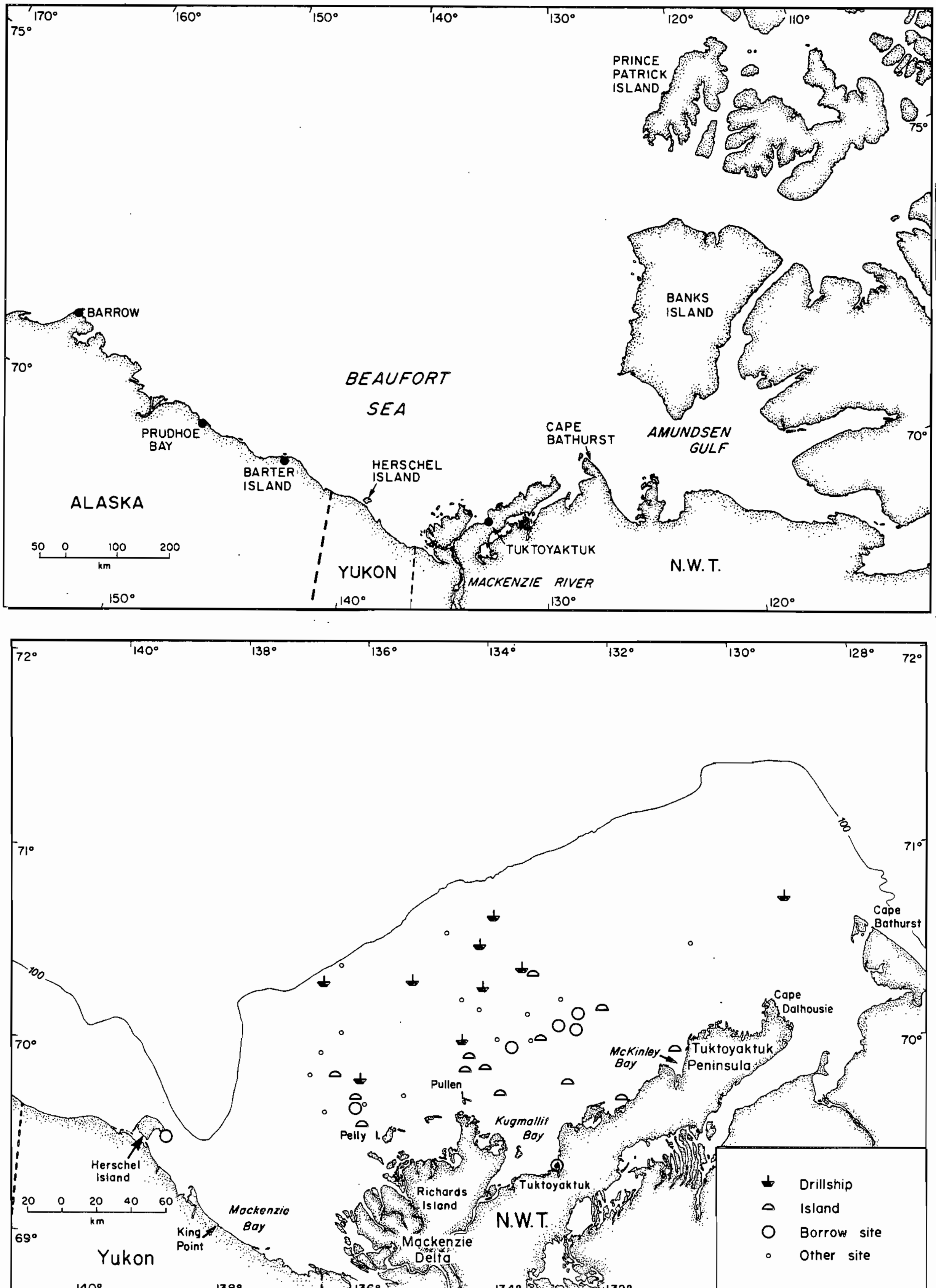

FIGURE 1. Maps of the Beaufort Sea region. Above: The general region. Below: The eastern Beaufort Sea, showing locations of offshore industrial activity in late summer during 1980-82.

Furthermore, there are major year to year differences in distribution at particular times during the summer.

To date, there has been no overall compilation or analysis of the distribution of summering bowheads in relation to the distribution of industrial activities in the eastern Beaufort Sea. The reports of individual studies done in 1980-82 sometimes comment on similarities and differences in bowhead distribution relative to previous studies, and on the presence or absence of whales near industrial activities, but this information has not been drawn together in a systematic way. Furthermore, the distributional data collected incidental to behavioral studies during the present project have not been reported previously.

It may be too early to detect whether long term changes in summer distribution of bowheads have occurred recently, given the scarcity of data from years before 1980 and particularly from years before offshore oil exploration began. However, the data for 1980-82 should be useful as a basis for formulating hypotheses and designing studies about factors affecting bowhead distribution. The data should also be useful as a basis for comparison in the future even if no definite conclusions about industrial effects can be drawn now. Many of the data concerning both whale distribution and industrial activity are unpublished and increasingly difficult to locate as time passes. Hence, they should be compiled now if they are ever to be compiled.

The objectives of this report are twofold: (1) Draw together in a standardized way the available published and unpublished information about bowhead distribution and industrial activities in the eastern Beaufort Sea during the summers of 1980 to 1982. (2) Assess whether there are any consistent trends in the summer distribution of bowheads during this period, and whether any such trends can be related to industrial activities.

Our approach has been to compile the available data into a series of maps for each 1/3 month period within each of the three years studied. The maps cover the area from the Alaska-Yukon border eastward beyond Cape Bathurst, and from the shore north beyond the edge of the continental shelf to about 72°N. The area of offshore oil exploration is on the continental shelf in the center of the mapped area (Fig. 1). These maps are supplemented with explanatory text. After the available data are presented in the above format, we discuss the general trends that emerge from the data.

Several different types of maps are used. For each 1/3 month period, one map shows the sightings of bowheads during the various aerial survey projects, and includes information about the areas that were and were not surveyed. Another map shows the locations where seismic surveys were conducted. A third map shows the locations of offshore industrial activities such as drilling or dredging, and indicates the routes travelled by vessels during that period. A fourth map showing helicopter routes and ice conditions was prepared for each 1/3 month period, but only about half of these maps are included here. For certain periods, we include additional maps showing bowhead sightings during systematic aerial surveys.

The results of this analysis can be understood from the maps and accompanying text in the 'Results' section without reading the following 'Methods and Data Sources' section. However, the Methods section does document the sources and limitations of the data, and the conventions that were used in compiling the information.

METHODS AND DATA SOURCES

Information about bowhead distribution in the eastern Beaufort Sea is available from early August to early September 1980, late July to early September 1981, and early August to early September 1982. Hence, we include maps for four 1/3 month periods in 1980, five periods in 1981, and four periods in 1982. The periods were chosen arbitrarily as being days 1-10, 11-21, and 22-31 of the month. We have not attempted to compile information about industrial activities during the early summer and the autumn periods for which there was little information about bowheads. However, bowheads are infrequent in the area of intense industrial activity off the Mackenzie Delta before late July and after early September (Fraker and Bockstoce 1980; this report).

Bowhead Sightings

For each 10 or 11 day period (hereafter referred to as 10-d period), we present one or two maps showing all aerial survey routes and bowhead sightings known to us.

Data Sources, 1980. -- The only systematic, repeated aerial surveys in 1980 were a series of three surveys off the Tuktoyaktuk Peninsula (Renaud and Davis 1981) and seven surveys of a small area around Issungnak artificial island off the Mackenzie Delta (Norton Fraker and Fraker 1981; Fraker et al. 1982). The former three surveys were funded by Dome and Gulf, and were conducted on 6-7 August, 21-24 August, and 3-4 September. Each survey consisted of a series of north-south flight lines spaced 8 km apart and extending from near the shore out to the 50-m depth contour. The seven surveys over the shallow waters around Issungnak were funded either by Esso or by the U.S. Bureau of Land Management as part of the present project. They were conducted between 24 July and 22 August. The area covered was much smaller, but the flight lines were closer together (3.2 km) to provide intensive coverage. Details are given in the original reports.

Additional aerial surveys in the eastern Beaufort Sea in 1980 were reported by Hobbs and Goebel (1982) and Ljungblad (1981). Hobbs was attempting to place radio transmitters on summering bowheads, and Ljungblad flew aerial surveys in support of Hobbs. Some of their flights extended seaward to or beyond the edge of the continental shelf, although most were closer to shore. In cases where the routes mapped in the two reports differed slightly, we used the route shown by Hobbs and Goebel. It was generally not evident from their reports how many whales were seen at each sighting location, so special symbols for 'unknown number' have been used on our maps.

Flight routes and sightings of bowheads were also recorded during our study of bowhead behavior and disturbance in 1980. This information has not been reported previously. The data span the period 3-31 August. The general procedures, although not the flight lines or sighting locations, are given in Richardson (ed., 1982). Because many bowheads were found in shallow water close to shore, these flights were restricted to the inner half of the continental shelf.

Data Sources, 1981. -- Four extensive, systematic surveys of the eastern Beaufort Sea were conducted in late July, mid and late August, and early September (Davis et al. 1982). This work was funded by many companies in the Alaskan and Canadian oil industry (organized by Sohio Alaska and Dome), plus the State of Alaska. These surveys were planned to extend from the Alaska-Yukon border east through Amundsen Gulf, and from the shore north to the deep waters beyond the shelf. During each survey, some parts of the area could not be covered because of poor weather, but extensive coverage was obtained in each period. Flight lines were oriented north-south, nominally at either 16 or 8 km intervals. We have re-mapped the results for the eastern Beaufort Sea, excluding Amundsen Gulf, using the same format as for all other sightings. For clarity, the results of these four systematic surveys are on maps separate from those summarizing other 1981 results.

Much additional survey coverage was obtained from late July through early September 1981 as a result of three projects:

(1) Davis et al. (1982) conducted a number of reconnaissance, behavioral observation, and whale photography flights in addition to their systematic surveys. Only a few of the resulting data were included in their report, but all have been included here.

(2) During the study of whale behavior and disturbance for BLM, we recorded our flight routes and sightings. The flights were more extensive in 1981 than in 1980 because whales were not as accessible close to shore. At various times from 27 July to 8 September, we covered areas from the shore to beyond the edge of the continental shelf, and from west of Herschel Island to Cape Bathurst. The routes and sightings are mapped here for the first time; general information about the procedures appears in Richardson (ed., 1982).

(3) Ljungblad et al. (1982) surveyed primarily in Alaskan waters during the summer of 1981. However, on 15, 17 and 19 August and several occasions in September, their flights extended east into the Canadian Beaufort Sea, sometimes as far as the Mackenzie Delta. We have included their flight routes and sightings on our maps for mid August and early September.

Data Sources, 1982. -- In 1982, the available data came from extensive non-systematic surveys during the present behavior study and during the whale photography study of Davis et al. (1983), from two systematic surveys by Harwood and Ford (1983), and from surveys in the western part of the Canadian Beaufort Sea by Ljungblad et al. (in prep.).

During the behavior study, we again covered areas from the shore north to beyond the continental shelf, and from west of Herschel Island to east of Cape Bathurst. Flights spanned the period 1 to 31 August. General procedures are given elsewhere in this volume by Würsig et al. (1983) and Richardson et al. (1983b); flight routes and sighting locations are mapped here. On behalf of the U.S. National Marine Fisheries Service, Davis et al. (1983) covered much of the same area on 12 August-5 September 1982 while searching for whales to be measured and identified by photogrammetry. Their routes and sightings are all mapped here, in combination with those from the behavior study.

Ljungblad et al. (in prep.) conducted surveys near the western edge of our study area (mainly west of Herschel Island) on various dates from 2 August until 14 October. We have included their flight lines and bowhead sightings on our maps for the 1 August to 10 September period.

With funding from Dome and Gulf, Harwood and Ford (1983) conducted two extensive, systematic surveys of the eastern Beaufort Sea on 18-24 August and 5-13 September 1982. They flew north-south lines, generally spaced 16 km apart, from west of Herschel Island to the eastern end of the Tuktoyaktuk Peninsula. The lines extended from near shore to the 100 m contour or beyond. We have re-mapped their results into our standard format. For clarity, we present their results on maps separate from those showing results of the other studies.

Procedures for Compiling Data. -- All of the aircraft used for the surveys had accurate Very Low Frequency (VLF) navigation systems. With very few exceptions, the flight routes and sighting locations were precisely known. Because many of the flights were not systematic surveys with defined transect widths, we have mapped all sightings, whether or not they were classified as on- or off-transect in the original reports.

The exact number of whales seen at each location could not be shown in compact format. Instead, symbols of progressively increasing prominence are used to show sightings of 1-3, 4-7, 8-15, 16-30 or 31-80 bowheads. When two or more sightings within a 10-d period were so close together that their symbols overlapped broadly, they are shown as a single symbol.

On the main map for each 10-d period, we have used a format that distinguishes sightings and routes during the first 5 days from those during the next 5 or 6 days. Triangular symbols and dashed lines are used for days 1-5; circles and solid lines are used for days 6-10 or 6-11. This level of detail is rarely needed for the broad-scale interpretations in this report. However, it may be useful for other purposes. Surveys conducted on 12-16 September 1980 and 12 September 1981 are included on the early September maps for those years; flight routes are shown as dotted lines.

In some 10-d periods, there was so much aerial survey activity within certain areas that it was impractical to show every flight line. These 'intensive coverage areas' are demarcated with a heavy line; within these areas only the bowhead sightings, not the flight routes, are shown. In some cases, systematic survey coverage within an 'intensive coverage area' is shown in a separate inset map.

The maps based on non-systematic surveys provide only a qualitative indication of the relative abundance of bowheads in different areas, and therefore must be interpreted with caution. Survey procedures differed between projects, and detectability of whales was better during some flights than others. Survey effort in different parts of the study area ranged from nil to intensive, and non-systematic surveys tended to be concentrated in areas with many bowheads. Some whales were undoubtedly counted more than once in a 10-d period, especially in areas where there was much survey coverage.

Seismic Exploration and Sounding

Seismic exploration has occurred in the Canadian Beaufort Sea most if not all summers since the 1960's. Seismic exploration via high-energy techniques produces by far the most intense underwater sounds of any normal offshore activities of the oil industry (Greene 1982, 1983). Hence, we present a series of maps dealing specifically with locations of seismic exploration and sounding, a related activity. There is one map for each 10-d period during 1980-82. Solid lines depict geophysical surveys shot by two vessels using large arrays of airguns -- the 'GSI Mariner' and, in 1981, the 'Edward O. Vetter'. Dashed lines depict surveys by the 'Arctic Surveyor', a vessel with an array of 12 large sleeve exploders (1980-81) or open-bottom gas guns (1982).

The exact locations of the seismic lines and the dates on which they were shot were kindly provided by Geophysical Service Inc., Dome Petroleum Ltd., and Esso Resources Canada Ltd., all of Calgary. Supplementary information was obtained from our records of the locations and dates in 1980-82 when seismic vessels were seen at sea during the behavior study. Some information about locations of seismic exploration is considered proprietary by the companies involved. We know that some additional lines besides those on our maps were shot, but we do not know the specific locations.

Detailed information about the sounds produced by the three vessels mentioned above appears in Greene (1982, 1983). The 'Mariner' uses a 1410 cu in airgun array with source level 246 dB//1 μPa at 1 m. The 'Vetter', a larger ship, uses a 2000 cu in array. These vessels normally travel continuously along the survey line at 4 or 5 knots, firing the airguns every 12-16 seconds. The 'Arctic Surveyor' fires several shots at one location at 6-10 s intervals, and then moves a few tens of metres ahead before firing the next series of shots. In this 'stop and go' mode, the 'Arctic Surveyor' progresses along the survey line at a much slower rate than does a ship operating in a continuous tow mode.

In 1982, the 'Canmar Teal' used a smaller array of airguns to conduct high resolution seismic surveys within several small areas off the Mackenzie Delta. She used an array of three airguns with total volume 300 cu in. Most of the areas she surveyed were 3 km x 3 km in size, and the shot lines were spaced 200 m apart in one direction and 400 m apart in the other (F.J. Quinn, Geoterrex Ltd., pers. comm.). The source level of the array was reportedly 6 to 7 bar-m, zero to peak, or about 236 dB//1 μPa at 1 m. Grids shot by 'Canmar Teal' in 1982 are shaded on the maps, and additional single lines of shots are dotted. The information about shooting locations was provided by Dome, Gulf and Geoterrex.

Numerous vessels used a variety of lower-energy sounding techniques and/or coring to assess water depths and bottom conditions, search for gravel deposits, etc. Dome, Esso and Gulf provided information about some of the locations where the 'Arctic Sounder', 'Betty Coulter', 'Canmar Teal, 'Canmar Widgeon', 'Frank Broderick', 'J. Mattson', 'Mary B IV', 'Mary B VI', 'Norweta', and 'Ublureak' conducted such surveys during one or both of 1981-82. No information about sounding was available for 1980. The Canadian Hydrographic Service, Institute of Ocean Sciences, provided information about locations where the 'CSS Hudson' used small airguns (5 or 10 cu in) in 1981. Sounding areas that were smaller than 1 km x 1 km are mapped as open dots. Sounding locations of larger dimensions are shown as lightly shaded areas or as lines of widely spaced dots. Our information about these low-energy activities is incomplete. On the other hand, some cases recorded as 'sounding' were probably coring, and it would have been more appropriate to map those on the 'vessel traffic' maps rather than on the 'seismic and sounding' maps.

Offshore Industrial Sites and Vessel Movements

The third type of map presented for each 10-d period shows the offshore locations where industrial activities were taking place, and the number of vessel movements along each route. The main activities at specific offshore sites were dredging, island construction or maintenance, drilling from islands or drillships, and island clean-up. Most of these activities are shown by separate symbol types. The activity is mapped even if it occurred for only 1 day within the 10-d period. This accounts for the presence of five drillship symbols on some maps, despite the fact that only four drillships were present each year from 1980 to 1982.

Dredge borrow sites, where material was removed from the bottom for transport to some other site, were distinguished from sites where dredged material was deposited at an immediately adjacent island construction site. Drillship locations are identified as such whether or not drilling was actually occurring during the 10-d period. The only case of active drilling from an artificial island during the periods mapped was at Tarsiut Island during early August 1982. At other times, artificial islands are mapped as active (e.g. well testing or island clean up underway) or inactive. Inactive artificial islands close to shore are not mapped.

Vessel traffic, excluding seismic and sounding operations, is shown on the same maps. The approximate number of vessel trips along each route is shown by the thickness of the line. This information came from the records of the oil companies and Northern Transportation Company Ltd. Most of the offshore traffic appears to have been listed in the records that we searched. However, we undoubtedly missed some trips, particularly in 1980 -- the year for which the records were least complete. The vessel movements shown on our maps include passes by small crew-change boats and larger supply boats, tugs and barges, Dome's icebreaker, drillships moving between drilling sites, and movements by dredges. Characteristics of underwater noise from several of these vessels are described by Greene (1982, 1983).

In cases when the precise number of vessel trips between two sites was unknown, a minimum estimate of the number is indicated. Estimation was required most frequently for movements by hopper dredges and small crew-change boats. Direct straight-line routes were assumed unless these would cross unnavigable areas. All vessels travelling to and from Tuktoyaktuk harbor were assumed to have followed the channel and buoys.

We have not attempted to map the movements of research vessels; 1 or 2 were usually in the eastern Beaufort Sea. We have also excluded some vessel traffic that was restricted to nearshore areas, e.g. movements of the Coast Guard buoy tender 'Nahidik', and vessel traffic between coastal sites such as Tuft Point, Pullen Island, Hansen Harbour, and Tuktoyaktuk. Vessels operating between these sites generally stay in water <10 m deep where bowheads occur infrequently. We also did not map the local movements of support vessels around drillships and other offshore industrial sites.

comparable in level to those observed while she was underway empty. 'Gateway' was quieter than 'Geopotes X', but both hopper dredges were noisier than the suction dredge 'Beaver MacKenzie' dredging while at anchor at an island site.

Figure 24 presents a summary graph of received levels vs. range for industrial sources measured in the Beaufort Sea during August 1981-82. The dashed lines near the top are included to show the attenuation slopes for cylindrical spreading (10 log R) and spherical spreading (20 log R). The solid lines without data points represent regression models derived from the data. Greater attenuation with increasing range can be seen for shallower water by comparing the curves for seismic signals in 1981 and 1982 (shallower water in 1982). The 1981 data for 'Geopotes X' underway loaded may have been unusually elevated because of a damaged propeller. The points plotted for 'Gateway', Tarsiut island, and 'Geopotes X' in 1982 are 10-500 Hz band levels which include tonal powers in that band; the 1981 curves for the suction dredge, drillship, and 'Geopotes X' underway are only for the strongest tone present. The variable levels near Tarsiut artificial island are illustrated by the lower (118.6 dB) 10-500 Hz level measured at 0.46 km on 15 August as compared to the range of levels (126.1-133.3 dB) measured at 1.1 km on 6 August. From Figure 24, it is obvious that seismic signals are by far the strongest sounds introduced into the Beaufort Sea by the kinds of industrial activities that we have studied.

The 'Drillship, 278 Hz' curve in Figure 24 represents Explorer II while she was drilling. The strongest tones recorded at drillship Explorer I during logging were on the order of 20 dB below the strongest tones from Explorer II during drilling at comparable ranges. The drilling noises from Explorer III at ranges of 11 and 18.5 km were below the ambient, which is consistent with the attenuation trend measured for Explorer II drilling.

Hopper dredges, capable of taking up a load from the bottom at one place and carrying it to another place for dumping, appear among the stronger sources of industrial noise as shown in Figure 24. Dredge 'Geopotes X' both underway and dredging was noisier than other vessels measured, while dredge 'Gateway' produced slightly weaker sounds underway and dumping.

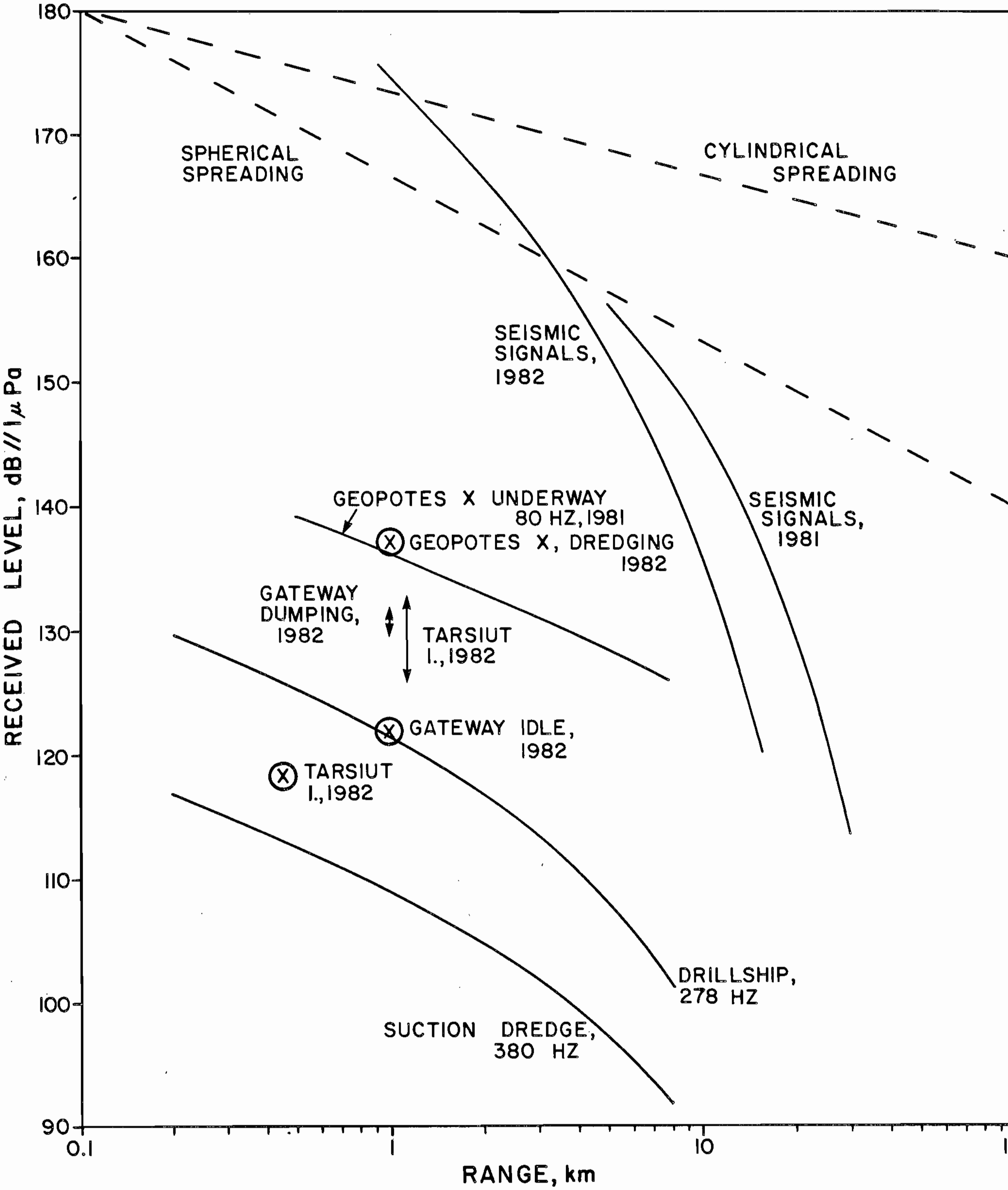

FIGURE 24. Received levels of underwater sounds from various industrial sources in relation to range, eastern Beaufort Sea, 1981-82.

Most of the energy in the various industrial sounds that we have recorded in the eastern Beaufort Sea is at frequencies below a few hundred Hertz. Most bowhead calls are also predominantly in this frequency range (Ljungblad et al. 1982; Würsig et al. 1982). Although the auditory sensitivity of bowheads has not been studied, we assume that they can detect low frequency sounds, including both their own calls and various industrial sounds. The possible effects of industrial noise on bowheads include both disturbance and masking of other sounds (e.g., masking of calls from distant bowheads). These possibilities, and the potential consequences, are discussed in the 'Disturbance' section of this report (Richardson et al. 1983c) and, more comprehensively, in Richardson et al. (1983b).

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DISTRIBUTION OF BOWHEADS AND INDUSTRIAL ACTIVITY, 1980-82*

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ABSTRACT

A preceding section on 'Disturbance Responses of Bowheads' examined short-term behavioral responses of summering bowheads to activities associated with offshore oil exploration. However, the behavioral approach cannot determine whether these activities result in long-term displacement. This section reviews the distribution of bowheads summering in the eastern Beaufort Sea in recent years and discusses whether there have been any distributional changes attributable to oil exploration.

Methods. -- Detailed data on bowhead distribution in most of the Canadian Beaufort Sea have been collected only since 1980, and only from late July or early August to mid September. Sightings during the various studies conducted within this period are compiled here onto a series of maps, one or two per 10-d period. Survey routes are also shown on these maps. Previously unreported distributional data from this and other LGL studies in 1980-82 are included, along with results compiled from all available reports by ourselves and others.

Industrial activities are also mapped. For each 10-d period, we include one map showing the sites of offshore drilling, dredging, etc., along with the approximate number of boat trips along each route. Another map for each 10-d period shows seismic lines shot during the period, plus locations of low-energy sounding. A third type of map shows helicopter traffic and ice conditions during the 1-10 and 22-31 August periods. 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 support traffic via boat and helicopter.

In **1980**, bowheads were more numerous close to shore than in the subsequent two years. Around 2 August, many moved into shallow waters off the central Mackenzie Delta, the main industrial area. Some were within 5 km from the island construction operation at Issungnak. Whales were scarce farther east off the Tuktoyaktuk (Tuk) Peninsula in early August, but moved into that area of lesser industrial activity in mid August. By late August, very large numbers were widely distributed off the Tuk Peninsula, many in

water <20 m deep. Numbers off the Delta were somewhat reduced, but still high. Previous to late August, there was no survey coverage west of the Delta; in late August at least a few whales were present north of Herschel Island. In early September, fewer whales were found off the Tuk Peninsula, and they were farther offshore. Numbers off the Delta were much reduced, but whales were seen regularly near Herschel Island. Bowheads were first seen in Alaskan waters on 4 September.

In **1981**, survey coverage was more comprehensive and most bowheads remained farther offshore. In late July, most were either far offshore in pack ice or in Amundsen Gulf. In early August many moved south onto the outer continental shelf off the Mackenzie Delta, with lesser numbers off the Tuk Peninsula. None were seen near Issungnak where whales were abundant in early August 1980. In mid August the whales were more evenly distributed from Herschel Island to Cape Bathurst, mainly in waters >50 m deep, but there was a concentration in shallower water off the central Delta. Some of the latter animals were <10 km from an artificial island and drillship. In early September, most bowheads were still in Canadian waters, with many off the Tuk Peninsula and Herschel Island and lower densities elsewhere. The first sighting in Alaskan waters was on 7 September.

In **1982**, most bowheads were far enough offshore or west to be outside the main industrial area. In early August, the only sightings in the Canadian Beaufort Sea were on the outer shelf off the western Delta and Yukon, and many were moving west. Some bowheads were seen in the Alaskan Beaufort as early as early August. In mid August, there was a major concentration near Herschel Island, with low densities off the Delta and Tuk Peninsula. In late August, many bowheads remained off Herschel Island; others were along the shelf break off the western Delta and on the outer shelf off the eastern Tuk Peninsula. In early September, many were still near Herschel Island, with a few on the outer shelf off the Delta and Tuk Peninsula.

Discussion. -- Most of the Canadian Beaufort Sea was not surveyed for bowheads before 1980. However, a longer series of data is available for the area of most intense industrial activity off the eastern Mackenzie Delta.

Island construction and traffic to drillships farther north have occurred off the Delta each summer since 1976, and seismic exploration since 1971. In 1976 and 1977, many bowheads entered shallow waters off the Delta in early August. They did not do so in 1978 or 1979. Many whales occurred off the eastern part of the Delta in 1980, but few were there in 1981 and almost none in 1982. Given the reappearance of many whales off the Delta in 1980, there is no clear trend for decreasing numbers in that small area. For other parts of the Canadian Beaufort Sea, the lack of data from years before 1980 makes it impossible to assess whether the 1981 and 1982 distributions were unusual.

In 1980, 1981 and 1982, seismic exploration occurred over much of the Canadian Beaufort Sea -- both within and beyond the main industrial area. Numerous bowheads were in areas ensonified by seismic noise in 1981 and 1982 as well as in 1980.

Whether or not industrial activities affect bowhead distribution in summer, bowhead movements probably depend strongly on the distribution and abundance of zooplankton. Factors affecting zooplankton in the eastern Beaufort Sea are poorly known, but probably include the variable volume and movement of fresh water from the Mackenzie River, and hydrographic phenomena at the shelf break and the ice edge. The variable distribution of ice probably also has direct effects on whale distribution.

INTRODUCTION

The primary focus of the study reported in this volume has been the short-term behavioral reactions of bowheads to actual and simulated industrial activities. Behavioral responses are studied primarily because a positive response provides an immediate indication that the whales may be sensitive to the industrial activity. We have studied the behavior of bowheads in the presence of boats, aircraft, seismic exploration, drillships and dredging (Fraker et al. 1982; Richardson et al. 1983b).

The long term reactions of the bowhead population to offshore industrial activity are ultimately of greater concern than are short term behavioral responses. Long term reactions might, in theory, include such interrelated factors as increased stress, reduced overall food intake during the summer feeding season, reduced reproductive success or survival rate, and displacement from parts of the traditional range. All of these medium to long term effects are difficult to detect. Even if detected it would be difficult to determine whether they were attributable to industrial activity rather than to some form of natural variation.

The one type of long term effect on bowheads that might be detectable from data now being collected is displacement from parts of the traditional range. Gray whales were apparently displaced from at least one of their wintering lagoons when ship traffic and other human activities intensified, and returned years later when ship traffic decreased (Reeves 1977). In other cases, suggested displacements of baleen whales by prolonged human activities have not been demonstrated convincingly (reviewed by Richardson et al. 1983a). These possible cases include other gray whale wintering areas and migration routes (Rice 1965; Rice and Wolman 1971; Wolfson 1977; Dohl and Guess 1979), humpback whale wintering and feeding areas (Norris and Reeves 1978; Jurasz and Jurasz 1979; MMC 1979/80), and whales in areas of heavy ship traffic off Japan (Nishiwaki and Sasao 1977). Most of these data are equivocal regarding whether whales are displaced by industrial activities. However, it is clear that they often return each year to areas where they have been hunted from ships or exposed to heavy vessel traffic.

Aerial surveys provide the type of comprehensive information about bowhead distribution that can be used in detecting changes in distribution. This technique has been used extensively to detect seasonal changes in distribution during migration around Alaska and during the summer in the Canadian Beaufort Sea. If continued over a period of years, aerial surveys could show whether long term changes in distribution had occurred.

Comprehensive aerial surveys have been done in Alaskan waters during the spring and fall migration seasons in 1979 (Ljungblad et al. 1980), 1980 (Ljungblad 1981), 1981 (Ljungblad et al. 1982) and 1982 (Ljungblad pers. comm.). The National Marine Fisheries Service conducted aerial surveys in some earlier years. These results provide valuable background data from years before there was much offshore oil exploration, aside from geophysical exploration, in the Alaskan Beaufort Sea.

In the eastern Beaufort Sea where the Western Arctic stock of bowheads spend the summer, systematic aerial surveys for bowheads did not begin until 1980. Before 1980, the only available data on summer distribution were from logbooks of commercial whalers who operated in the area at the start of this century, and incidental sightings by scientists and industry personnel engaged in offshore work (Fraker 1979; Fraker and Bockstoce 1980). These records suggested that most bowheads spend the early summer in Amundsen Gulf and the extreme eastern part of the Canadian Beaufort Sea--east of the area of offshore oil exploration (Fig. 1)--and then move westward off the Tuktoyaktuk Peninsula, Mackenzie Delta and Yukon coast in August and September.

By 1980, when systematic aerial surveys and other studies of bowheads in their summering areas began, full-scale offshore oil exploration had been underway for some years. Drilling from artificial islands in very shallow nearshore waters began in the early 1970's, and drillships began to work farther offshore in 1976. Systematic aerial surveys have continued on a larger scale in the summers of 1981 and 1982. The three summers of surveys have shown that many bowheads sometimes occur in the areas of most intense industrial activity. However, they have also shown that, at other times during the summer, bowheads are very scarce in the industrial area.

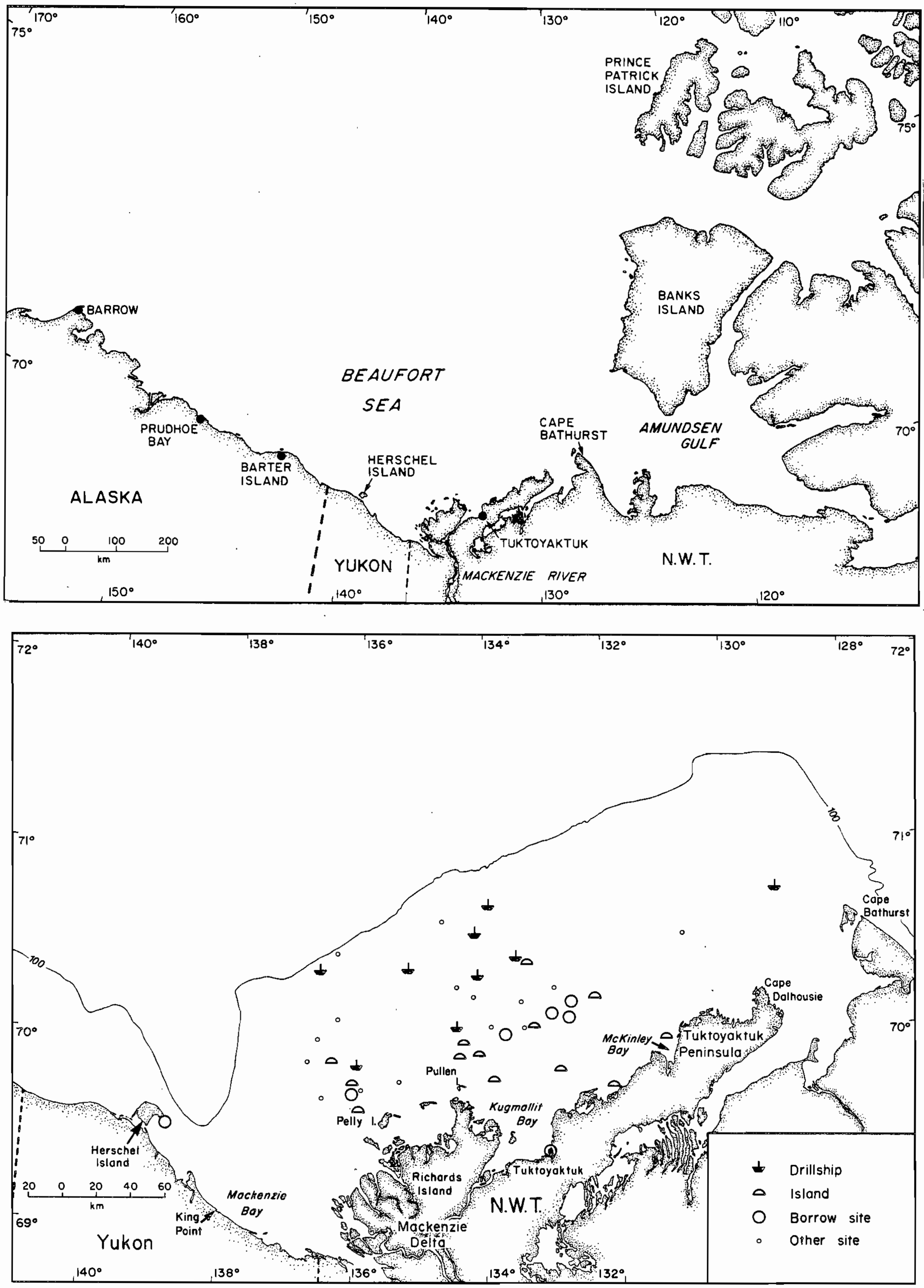


FIGURE 1. Maps of the Beaufort Sea region. Above: The general region. Below: The eastern Beaufort Sea, showing locations of offshore industrial activity in late summer during 1980-82.

Furthermore, there are major year to year differences in distribution at particular times during the summer.

To date, there has been no overall compilation or analysis of the distribution of summering bowheads in relation to the distribution of industrial activities in the eastern Beaufort Sea. The reports of individual studies done in 1980-82 sometimes comment on similarities and differences in bowhead distribution relative to previous studies, and on the presence or absence of whales near industrial activities, but this information has not been drawn together in a systematic way. Furthermore, the distributional data collected incidental to behavioral studies during the present project have not been reported previously.

It may be too early to detect whether long term changes in summer distribution of bowheads have occurred recently, given the scarcity of data from years before 1980 and particularly from years before offshore oil exploration began. However, the data for 1980-82 should be useful as a basis for formulating hypotheses and designing studies about factors affecting bowhead distribution. The data should also be useful as a basis for comparison in the future even if no definite conclusions about industrial effects can be drawn now. Many of the data concerning both whale distribution and industrial activity are unpublished and increasingly difficult to locate as time passes. Hence, they should be compiled now if they are ever to be compiled.

The objectives of this report are twofold: (1) Draw together in a standardized way the available published and unpublished information about bowhead distribution and industrial activities in the eastern Beaufort Sea during the summers of 1980 to 1982. (2) Assess whether there are any consistent trends in the summer distribution of bowheads during this period, and whether any such trends can be related to industrial activities.

Our approach has been to compile the available data into a series of maps for each 1/3 month period within each of the three years studied. The maps cover the area from the Alaska-Yukon border eastward beyond Cape Bathurst, and from the shore north beyond the edge of the continental shelf to about 72°N. The area of offshore oil exploration is on the continental shelf in the center of the mapped area (Fig. 1). These maps are supplemented with explanatory text. After the available data are presented in the above format, we discuss the general trends that emerge from the data.

Several different types of maps are used. For each 1/3 month period, one map shows the sightings of bowheads during the various aerial survey projects, and includes information about the areas that were and were not surveyed. Another map shows the locations where seismic surveys were conducted. A third map shows the locations of offshore industrial activities such as drilling or dredging, and indicates the routes travelled by vessels during that period. A fourth map showing helicopter routes and ice conditions was prepared for each 1/3 month period, but only about half of these maps are included here. For certain periods, we include additional maps showing bowhead sightings during systematic aerial surveys.

The results of this analysis can be understood from the maps and accompanying text in the 'Results' section without reading the following 'Methods and Data Sources' section. However, the Methods section does document the sources and limitations of the data, and the conventions that were used in compiling the information.

METHODS AND DATA SOURCES

Information about bowhead distribution in the eastern Beaufort Sea is available from early August to early September 1980, late July to early September 1981, and early August to early September 1982. Hence, we include maps for four 1/3 month periods in 1980, five periods in 1981, and four periods in 1982. The periods were chosen arbitrarily as being days 1-10, 11-21, and 22-31 of the month. We have not attempted to compile information about industrial activities during the early summer and the autumn periods for which there was little information about bowheads. However, bowheads are infrequent in the area of intense industrial activity off the Mackenzie Delta before late July and after early September (Fraker and Bockstoce 1980; this report).

Bowhead Sightings

For each 10 or 11 day period (hereafter referred to as 10-d period), we present one or two maps showing all aerial survey routes and bowhead sightings known to us.

Data Sources, 1980. -- The only systematic, repeated aerial surveys in 1980 were a series of three surveys off the Tuktoyaktuk Peninsula (Renaud and Davis 1981) and seven surveys of a small area around Issungnak artificial island off the Mackenzie Delta (Norton Fraker and Fraker 1981; Fraker et al. 1982). The former three surveys were funded by Dome and Gulf, and were conducted on 6-7 August, 21-24 August, and 3-4 September. Each survey consisted of a series of north-south flight lines spaced 8 km apart and extending from near the shore out to the 50-m depth contour. The seven surveys over the shallow waters around Issungnak were funded either by Esso or by the U.S. Bureau of Land Management as part of the present project. They were conducted between 24 July and 22 August. The area covered was much smaller, but the flight lines were closer together (3.2 km) to provide intensive coverage. Details are given in the original reports.

Additional aerial surveys in the eastern Beaufort Sea in 1980 were reported by Hobbs and Goebel (1982) and Ljungblad (1981). Hobbs was attempting to place radio transmitters on summering bowheads, and Ljungblad flew aerial surveys in support of Hobbs. Some of their flights extended seaward to or beyond the edge of the continental shelf, although most were closer to shore. In cases where the routes mapped in the two reports differed slightly, we used the route shown by Hobbs and Goebel. It was generally not evident from their reports how many whales were seen at each sighting location, so special symbols for 'unknown number' have been used on our maps.

Flight routes and sightings of bowheads were also recorded during our study of bowhead behavior and disturbance in 1980. This information has not been reported previously. The data span the period 3-31 August. The general procedures, although not the flight lines or sighting locations, are given in Richardson (ed., 1982). Because many bowheads were found in shallow water close to shore, these flights were restricted to the inner half of the continental shelf.

Data Sources, 1981. -- Four extensive, systematic surveys of the eastern Beaufort Sea were conducted in late July, mid and late August, and early September (Davis et al. 1982). This work was funded by many companies in the Alaskan and Canadian oil industry (organized by Sohio Alaska and Dome), plus the State of Alaska. These surveys were planned to extend from the Alaska-Yukon border east through Amundsen Gulf, and from the shore north to the deep waters beyond the shelf. During each survey, some parts of the area could not be covered because of poor weather, but extensive coverage was obtained in each period. Flight lines were oriented north-south, nominally at either 16 or 8 km intervals. We have re-mapped the results for the eastern Beaufort Sea, excluding Amundsen Gulf, using the same format as for all other sightings. For clarity, the results of these four systematic surveys are on maps separate from those summarizing other 1981 results.

Much additional survey coverage was obtained from late July through early September 1981 as a result of three projects:

(1) Davis et al. (1982) conducted a number of reconnaissance, behavioral observation, and whale photography flights in addition to their systematic surveys. Only a few of the resulting data were included in their report, but all have been included here.

(2) During the study of whale behavior and disturbance for BLM, we recorded our flight routes and sightings. The flights were more extensive in 1981 than in 1980 because whales were not as accessible close to shore. At various times from 27 July to 8 September, we covered areas from the shore to beyond the edge of the continental shelf, and from west of Herschel Island to Cape Bathurst. The routes and sightings are mapped here for the first time; general information about the procedures appears in Richardson (ed., 1982).

(3) Ljungblad et al. (1982) surveyed primarily in Alaskan waters during the summer of 1981. However, on 15, 17 and 19 August and several occasions in September, their flights extended east into the Canadian Beaufort Sea, sometimes as far as the Mackenzie Delta. We have included their flight routes and sightings on our maps for mid August and early September.

Data Sources, 1982. -- In 1982, the available data came from extensive non-systematic surveys during the present behavior study and during the whale photography study of Davis et al. (1983), from two systematic surveys by Harwood and Ford (1983), and from surveys in the western part of the Canadian Beaufort Sea by Ljungblad et al. (in prep.).

During the behavior study, we again covered areas from the shore north to beyond the continental shelf, and from west of Herschel Island to east of Cape Bathurst. Flights spanned the period 1 to 31 August. General procedures are given elsewhere in this volume by Würsig et al. (1983) and Richardson et al. (1983b); flight routes and sighting locations are mapped here. On behalf of the U.S. National Marine Fisheries Service, Davis et al. (1983) covered much of the same area on 12 August-5 September 1982 while searching for whales to be measured and identified by photogrammetry. Their routes and sightings are all mapped here, in combination with those from the behavior study.

Ljungblad et al. (in prep.) conducted surveys near the western edge of our study area (mainly west of Herschel Island) on various dates from 2 August until 14 October. We have included their flight lines and bowhead sightings on our maps for the 1 August to 10 September period.

With funding from Dome and Gulf, Harwood and Ford (1983) conducted two extensive, systematic surveys of the eastern Beaufort Sea on 18-24 August and 5-13 September 1982. They flew north-south lines, generally spaced 16 km apart, from west of Herschel Island to the eastern end of the Tuktoyaktuk Peninsula. The lines extended from near shore to the 100 m contour or beyond. We have re-mapped their results into our standard format. For clarity, we present their results on maps separate from those showing results of the other studies.

Procedures for Compiling Data. -- All of the aircraft used for the surveys had accurate Very Low Frequency (VLF) navigation systems. With very few exceptions, the flight routes and sighting locations were precisely known. Because many of the flights were not systematic surveys with defined transect widths, we have mapped all sightings, whether or not they were classified as on- or off-transect in the original reports.

The exact number of whales seen at each location could not be shown in compact format. Instead, symbols of progressively increasing prominence are used to show sightings of 1-3, 4-7, 8-15, 16-30 or 31-80 bowheads. When two or more sightings within a 10-d period were so close together that their symbols overlapped broadly, they are shown as a single symbol.

On the main map for each 10-d period, we have used a format that distinguishes sightings and routes during the first 5 days from those during the next 5 or 6 days. Triangular symbols and dashed lines are used for days 1-5; circles and solid lines are used for days 6-10 or 6-11. This level of detail is rarely needed for the broad-scale interpretations in this report. However, it may be useful for other purposes. Surveys conducted on 12-16 September 1980 and 12 September 1981 are included on the early September maps for those years; flight routes are shown as dotted lines.

In some 10-d periods, there was so much aerial survey activity within certain areas that it was impractical to show every flight line. These 'intensive coverage areas' are demarcated with a heavy line; within these areas only the bowhead sightings, not the flight routes, are shown. In some cases, systematic survey coverage within an 'intensive coverage area' is shown in a separate inset map.

The maps based on non-systematic surveys provide only a qualitative indication of the relative abundance of bowheads in different areas, and therefore must be interpreted with caution. Survey procedures differed between projects, and detectability of whales was better during some flights than others. Survey effort in different parts of the study area ranged from nil to intensive, and non-systematic surveys tended to be concentrated in areas with many bowheads. Some whales were undoubtedly counted more than once in a 10-d period, especially in areas where there was much survey coverage.

Seismic Exploration and Sounding

Seismic exploration has occurred in the Canadian Beaufort Sea most if not all summers since the 1960's. Seismic exploration via high-energy techniques produces by far the most intense underwater sounds of any normal offshore activities of the oil industry (Greene 1982, 1983). Hence, we present a series of maps dealing specifically with locations of seismic exploration and sounding, a related activity. There is one map for each 10-d period during 1980-82. Solid lines depict geophysical surveys shot by two vessels using large arrays of airguns -- the 'GSI Mariner' and, in 1981, the 'Edward O. Vetter'. Dashed lines depict surveys by the 'Arctic Surveyor', a vessel with an array of 12 large sleeve exploders (1980-81) or open-bottom gas guns (1982).

The exact locations of the seismic lines and the dates on which they were shot were kindly provided by Geophysical Service Inc., Dome Petroleum Ltd., and Esso Resources Canada Ltd., all of Calgary. Supplementary information was obtained from our records of the locations and dates in 1980-82 when seismic vessels were seen at sea during the behavior study. Some information about locations of seismic exploration is considered proprietary by the companies involved. We know that some additional lines besides those on our maps were shot, but we do not know the specific locations.

Detailed information about the sounds produced by the three vessels mentioned above appears in Greene (1982, 1983). The 'Mariner' uses a 1410 cu in airgun array with source level 246 dB//1 μPa at 1 m. The 'Vetter', a larger ship, uses a 2000 cu in array. These vessels normally travel continuously along the survey line at 4 or 5 knots, firing the airguns every 12-16 seconds. The 'Arctic Surveyor' fires several shots at one location at 6-10 s intervals, and then moves a few tens of metres ahead before firing the next series of shots. In this 'stop and go' mode, the 'Arctic Surveyor' progresses along the survey line at a much slower rate than does a ship operating in a continuous tow mode.

In 1982, the 'Canmar Teal' used a smaller array of airguns to conduct high resolution seismic surveys within several small areas off the Mackenzie Delta. She used an array of three airguns with total volume 300 cu in. Most of the areas she surveyed were 3 km x 3 km in size, and the shot lines were spaced 200 m apart in one direction and 400 m apart in the other (F.J. Quinn, Geoterrex Ltd., pers. comm.). The source level of the array was reportedly 6 to 7 bar-m, zero to peak, or about 236 dB//1 μPa at 1 m. Grids shot by 'Canmar Teal' in 1982 are shaded on the maps, and additional single lines of shots are dotted. The information about shooting locations was provided by Dome, Gulf and Geoterrex.

Numerous vessels used a variety of lower-energy sounding techniques and/or coring to assess water depths and bottom conditions, search for gravel deposits, etc. Dome, Esso and Gulf provided information about some of the locations where the 'Arctic Sounder', 'Betty Coulter', 'Canmar Teal, 'Canmar Widgeon', 'Frank Broderick', 'J. Mattson', 'Mary B IV', 'Mary B VI', 'Norweta', and 'Ublureak' conducted such surveys during one or both of 1981-82. No information about sounding was available for 1980. The Canadian Hydrographic Service, Institute of Ocean Sciences, provided information about locations where the 'CSS Hudson' used small airguns (5 or 10 cu in) in 1981. Sounding areas that were smaller than 1 km x 1 km are mapped as open dots. Sounding locations of larger dimensions are shown as lightly shaded areas or as lines of widely spaced dots. Our information about these low-energy activities is incomplete. On the other hand, some cases recorded as 'sounding' were probably coring, and it would have been more appropriate to map those on the 'vessel traffic' maps rather than on the 'seismic and sounding' maps.

Offshore Industrial Sites and Vessel Movements

The third type of map presented for each 10-d period shows the offshore locations where industrial activities were taking place, and the number of vessel movements along each route. The main activities at specific offshore sites were dredging, island construction or maintenance, drilling from islands or drillships, and island clean-up. Most of these activities are shown by separate symbol types. The activity is mapped even if it occurred for only 1 day within the 10-d period. This accounts for the presence of five drillship symbols on some maps, despite the fact that only four drillships were present each year from 1980 to 1982.

Dredge borrow sites, where material was removed from the bottom for transport to some other site, were distinguished from sites where dredged material was deposited at an immediately adjacent island construction site. Drillship locations are identified as such whether or not drilling was actually occurring during the 10-d period. The only case of active drilling from an artificial island during the periods mapped was at Tarsiut Island during early August 1982. At other times, artificial islands are mapped as active (e.g. well testing or island clean up underway) or inactive. Inactive artificial islands close to shore are not mapped.

Vessel traffic, excluding seismic and sounding operations, is shown on the same maps. The approximate number of vessel trips along each route is shown by the thickness of the line. This information came from the records of the oil companies and Northern Transportation Company Ltd. Most of the offshore traffic appears to have been listed in the records that we searched. However, we undoubtedly missed some trips, particularly in 1980 -- the year for which the records were least complete. The vessel movements shown on our maps include passes by small crew-change boats and larger supply boats, tugs and barges, Dome's icebreaker, drillships moving between drilling sites, and movements by dredges. Characteristics of underwater noise from several of these vessels are described by Greene (1982, 1983).

In cases when the precise number of vessel trips between two sites was unknown, a minimum estimate of the number is indicated. Estimation was required most frequently for movements by hopper dredges and small crew-change boats. Direct straight-line routes were assumed unless these would cross unnavigable areas. All vessels travelling to and from Tuktoyaktuk harbor were assumed to have followed the channel and buoys.

We have not attempted to map the movements of research vessels; 1 or 2 were usually in the eastern Beaufort Sea. We have also excluded some vessel traffic that was restricted to nearshore areas, e.g. movements of the Coast Guard buoy tender 'Nahidik', and vessel traffic between coastal sites such as Tuft Point, Pullen Island, Hansen Harbour, and Tuktoyaktuk. Vessels operating between these sites generally stay in water <10 m deep where bowheads occur infrequently. We also did not map the local movements of support vessels around drillships and other offshore industrial sites.

Because of these and other simplifications, our maps do not record every vessel movement, and the mapped routes are approximations. However, the maps are indicative of the relative amounts of traffic in various offshore areas and periods.

Helicopter Movements

For 1981 and 1982, we mapped helicopter traffic in the eastern Beaufort Sea area in the same general way as vessel traffic. The maps show the offshore industrial sites and the number of helicopter trips along each offshore route. The information was obtained from Dome, Esso and Gulf records. Information about a small proportion of their helicopter traffic in 1981-82 was not available, but the maps give a good depiction of the amount and distribution of traffic.

There were some uncertainties and assumptions about helicopter traffic in 1981-82. Hopper dredges moved about frequently, and we do not know their exact locations at the times that helicopters landed. We assumed that the dredges were at the borrow site during 50% of the flights, and at the dumping site for the other 50%. No helicopters aside from those of Dome, Esso and Gulf operated regularly over the eastern Beaufort Sea. However, a few of the single-engine helicopters operating in the area occasionally travelled offshore; we have not attempted to determine or map their activities. Helicopter traffic between onshore locations, e.g. from Tuktoyaktuk to McKinley Bay, was not mapped.

Helicopter traffic maps changed little from one 10-d period to the next. Hence, we present here only the maps for 1-10 and 22-31 August of 1981 and 1982.

No adequate records of helicopter traffic in 1980 were available and no helicopter maps were prepared for that year. Comparison of the helicopter and vessel traffic maps for 1981 and 1982 shows that helicopter and vessel movement patterns were similar. This no doubt was true in 1980 as well. The offshore and onshore termini were generally the same for boats and helicopters. However, the helicopters generally made more trips between Tuktoyaktuk and the various offshore sites than did the boats.

Offshore flights by fixed wing aircraft are not included on the maps of helicopter traffic. Fixed wing traffic over the eastern Beaufort Sea is of three main types: (1) scheduled or charter service between onshore locations, (2) ice reconnaissance flights, and (3) biological surveys. The first two types of flights are normally at medium or high altitudes and unlikely to affect whales (Richardson et al. 1983b). Biological surveys usually are at 457 m (1500 ft) a.s.l. or below. Virtually all biological surveys over offshore portions of the eastern Beaufort Sea during our study periods were whale surveys; the routes are mapped on the 'bowhead distribution' maps.

Ice Conditions and Bathymetry

Maps of ice conditions are included for the 1-10 and 22-31 August periods of 1980-82. These maps distinguish areas of open water, 1-30% ice cover, 31-79% cover, and 80+% cover. We prepared these maps from the Weekly Composite Charts compiled by Ice Forecasting Central, Atmospheric Environment Service, Environment Canada. Their maps are based on satellite photographs and ice reconnaissance flights. To minimize the number of maps in this report, the 1981-82 ice data are included on the helicopter traffic maps. Locations of pack ice sometimes changed by many kilometres within a few hours; thus, the generalized maps presented here provide only a rough indication of ice cover.

The 100-m depth contour is shown on Figure 1 and on all vessel traffic maps. A more detailed bathymetric map appears within the set of maps for each year (Fig. 9, 28, 46). Our map is based on isobaths on the International Map of the World--Firth River sheet, and Dome Petroleum Limited map E-BFT-100-03. In most parts of the study area, water depths increase very gradually out to the 100 m contour, and then increase rapidly. The 100 m contour is 110-140 km offshore from the Mackenzie Delta and Tuktoyaktuk Peninsula, but only 25-70 km offshore from most points along the Yukon coast. The 100 m contour is within 10 km from the shoreline at two locations within the study area -- off the east sides of Herschel Island and Cape Bathurst.

RESULTS

Bowhead Distribution and Industrial Activities in 1980

The information for 1980 appears in Figures 2 to 16. The period 1 August to 10 September is considered. Abbreviated names of offshore locations mentioned in the text are given on Figure 3 or, if not present there, on the first vessel traffic map where that site appears.

Industrial Activities, 1980

The general level of industrial activity in 1980 was lower than in 1981 or 1982. However, information on activities in 1980 was more difficult to obtain and less complete. Esso Resources Canada Ltd. and Dome Petroleum Ltd. were the only two oil companies operating offshore in 1980.

All drilling done during the 1980 study period was from the four Dome drillships. Three of the ships remained at specific wellsites throughout the period. The other drillship was at one well from 2 August to 8 September. It then moved to the Kilannik well, the easternmost location that has been drilled in the Beaufort Sea (Fig. 15).

Two suction dredges operated in the eastern Beaufort throughout the study period, but only one was offshore where bowheads might be encountered. The 'Beaver Mackenzie' completed the dredging for Issungnak artificial island, in 18 m of water off Richards Island, on 24 August. It then began dredging Alerk artificial island in shallower water north of Tuktoyaktuk (Fig. 11). The 'Aquarius' dredge operated in McKinley Bay all summer and into the fall.

Most vessel movements were in support of the island building or drilling activities. Northern Transportation Co. Ltd. (NTCL) vessels made several trips to points east and west of the study area (Figs. 3, 7, 11). Clean-up of abandoned artificial islands was restricted to sites in very shallow water.

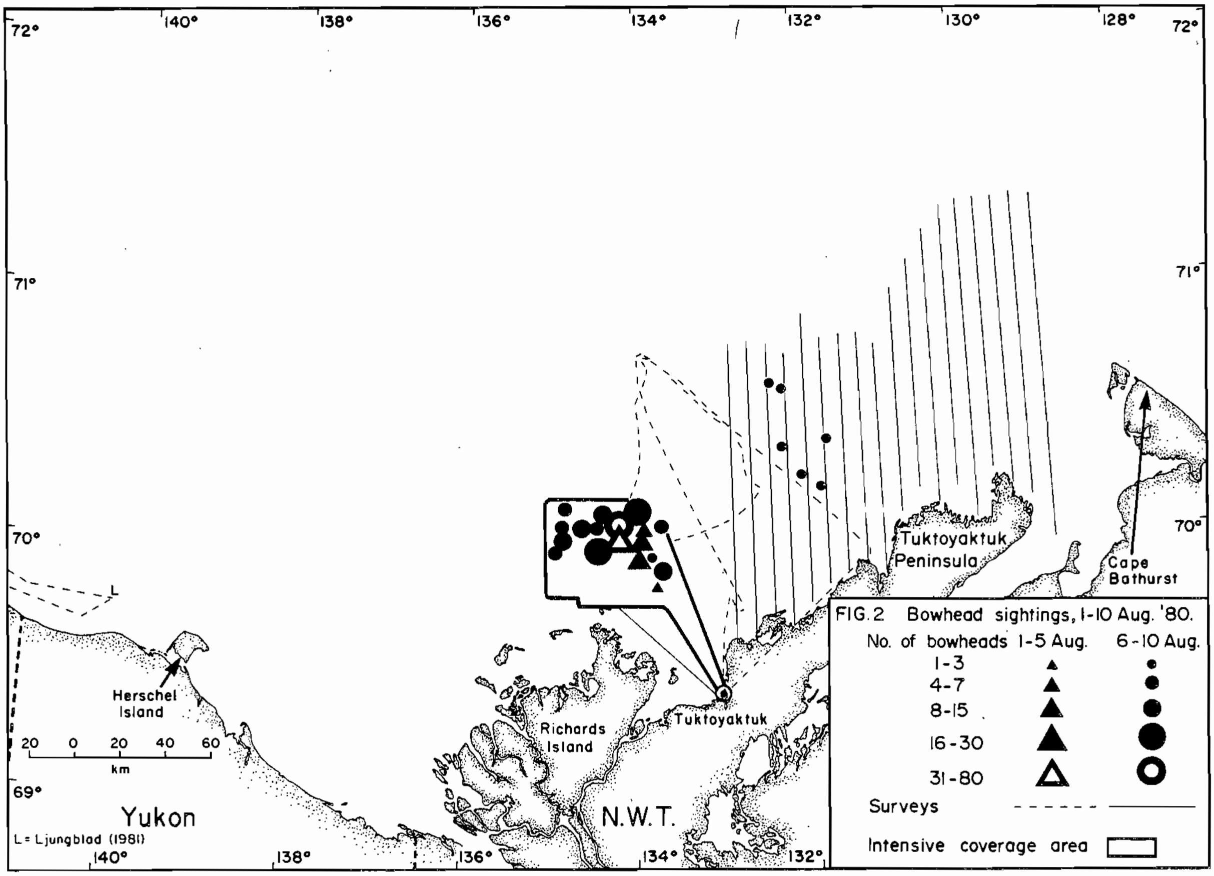


FIG. 2 Bowhead sightings, 1-10 Aug. '80.

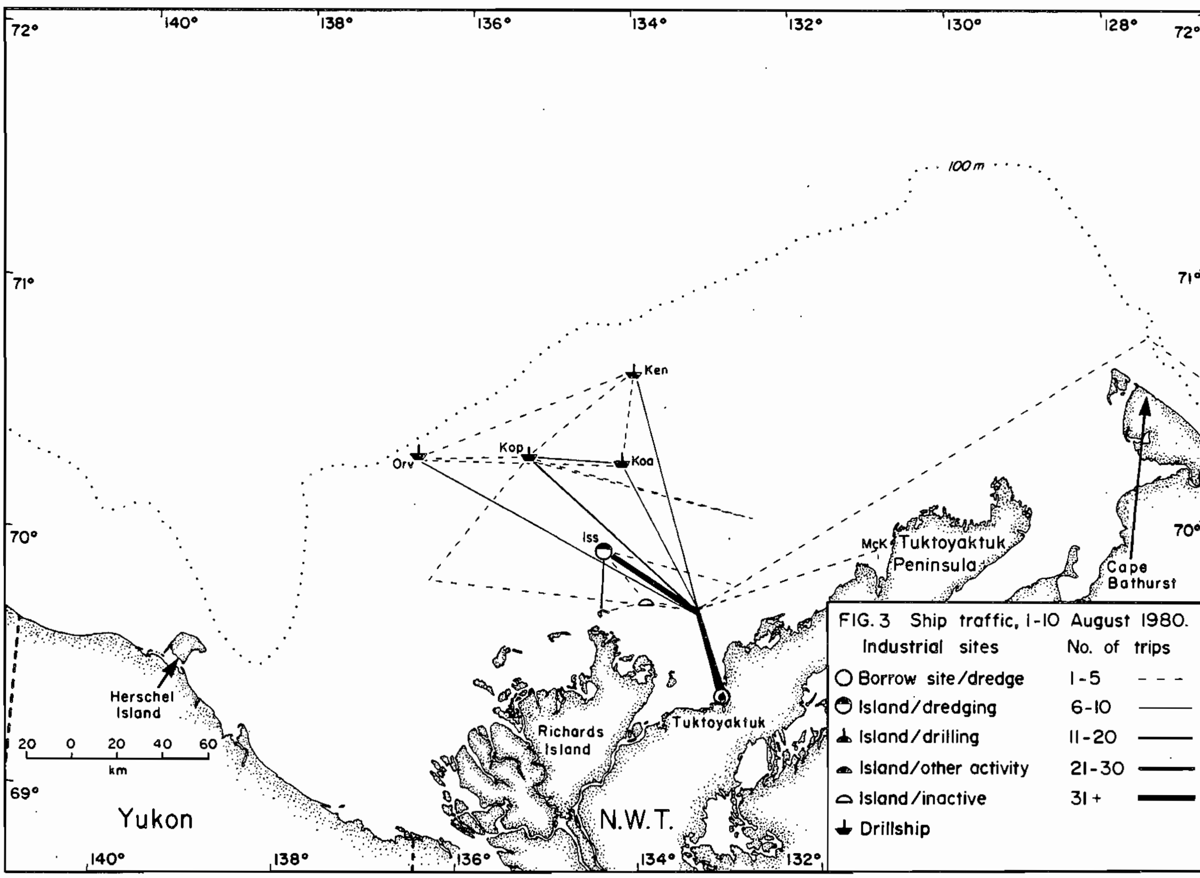


FIG. 3 Ship traffic, 1-10 August 1980.

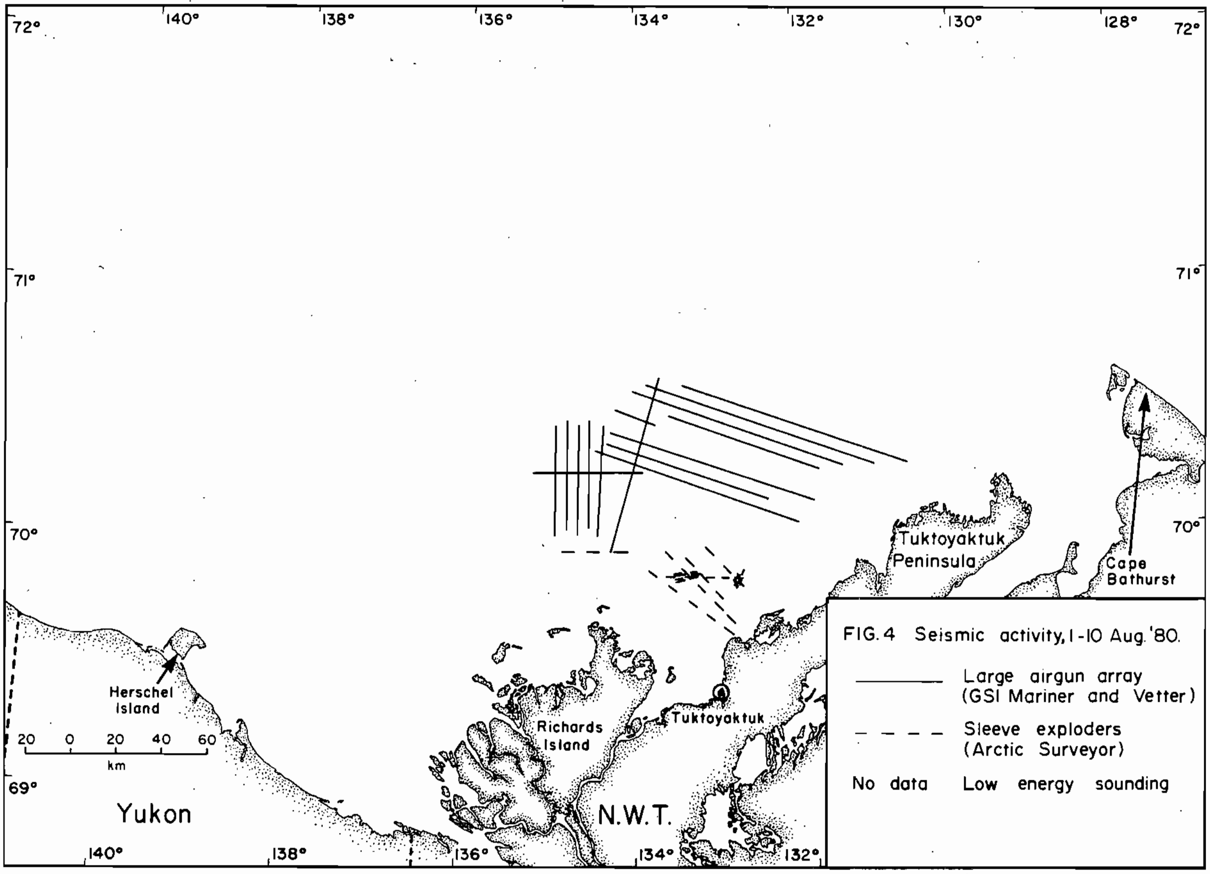


FIG. 4 Seismic activity, 1-10 Aug. '80.

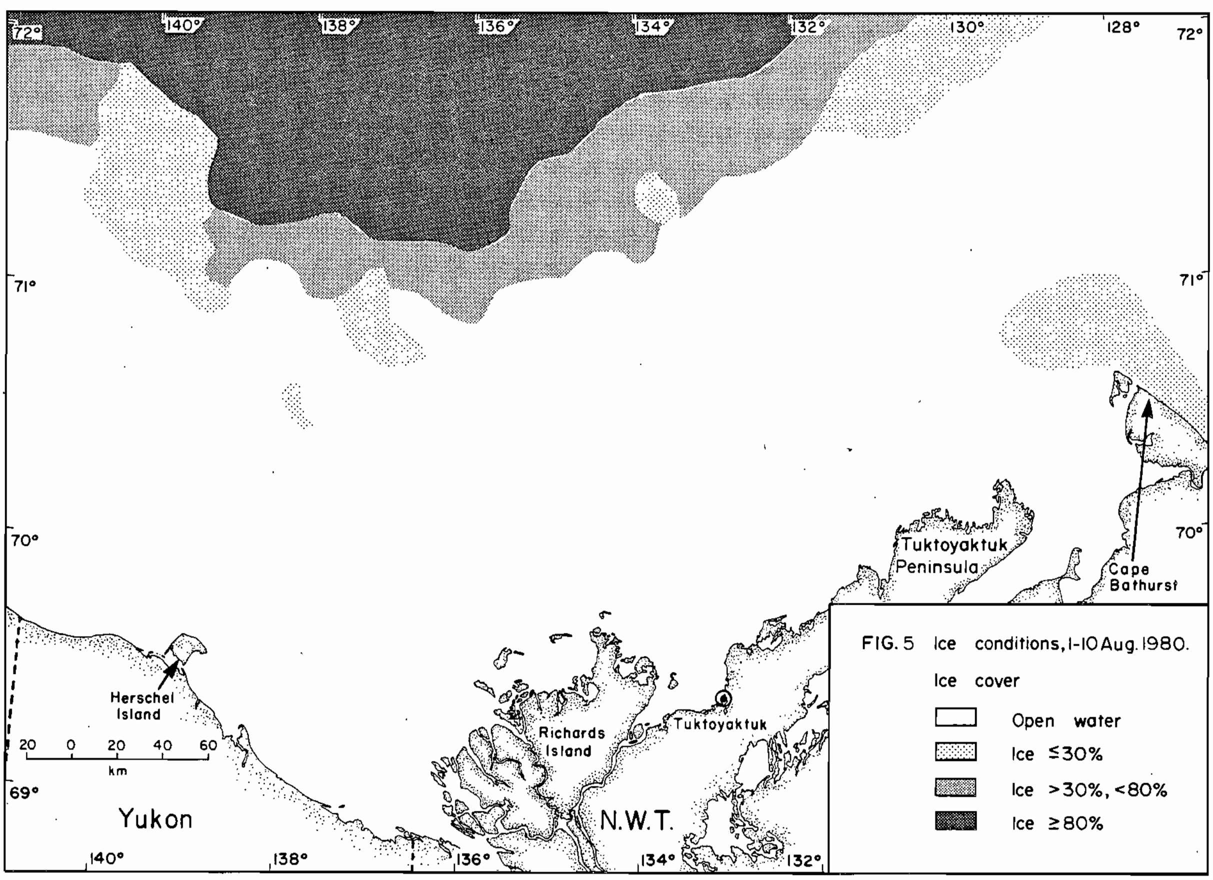


FIG. 5 Ice conditions, 1-10 Aug. 1980.

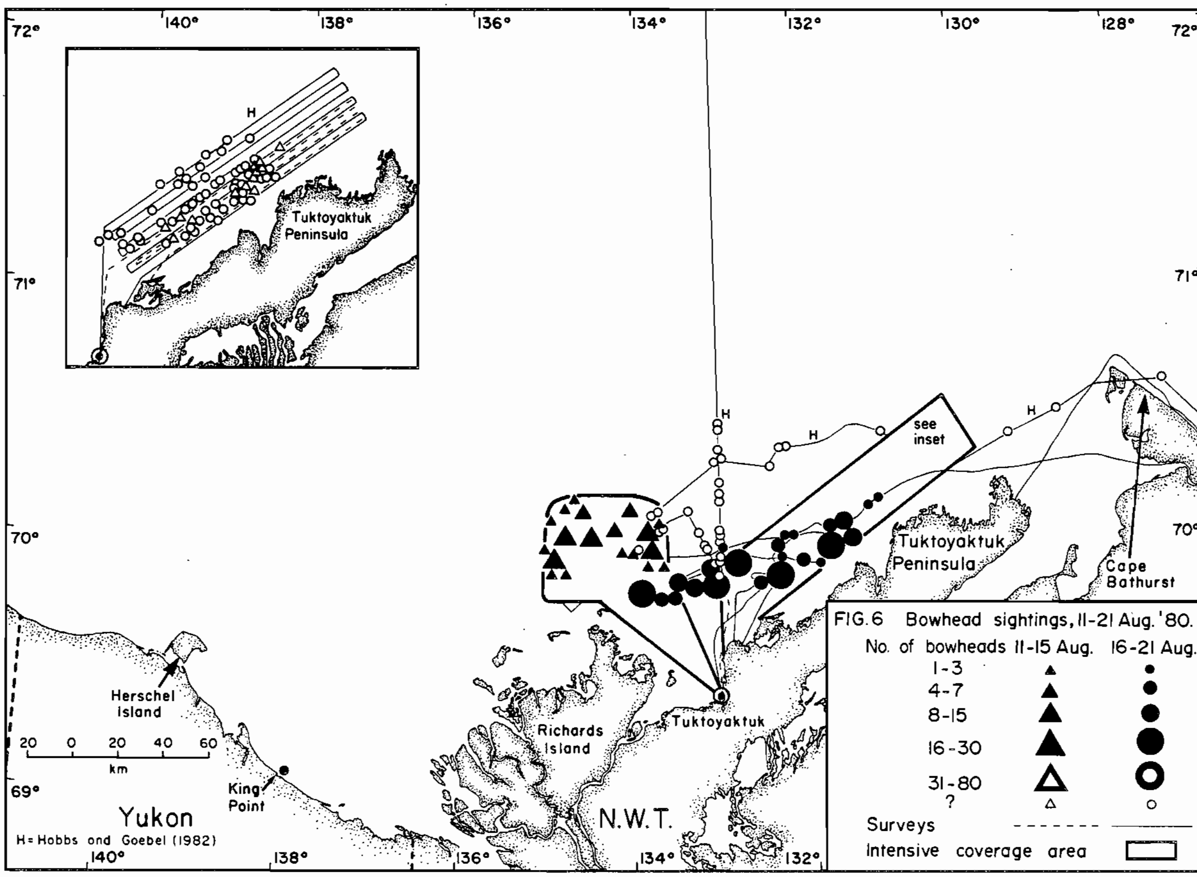


FIG. 6 Bowhead sightings, 11-21 Aug. '80.

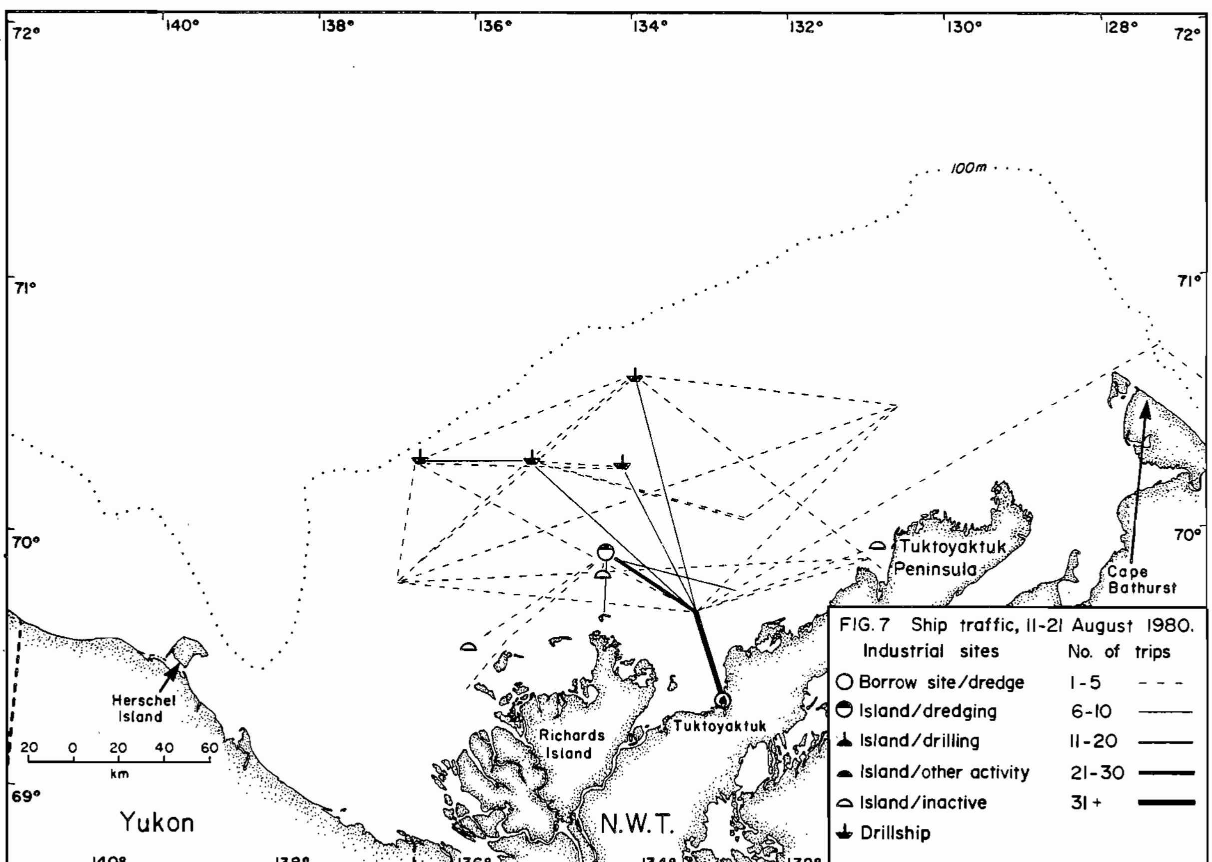


FIG. 7 Ship traffic, 11-21 August 1980.

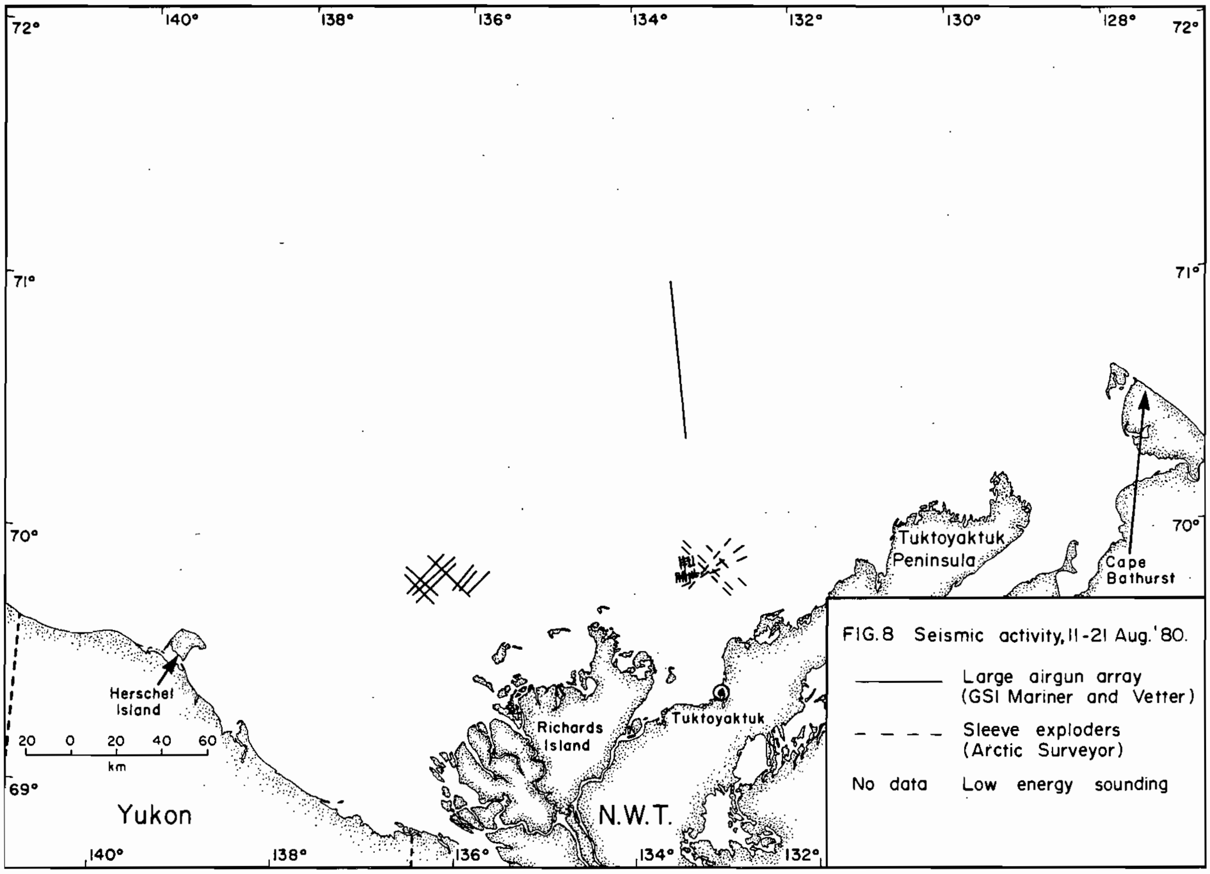


FIG. 8 Seismic activity, 11-21 Aug.'80.

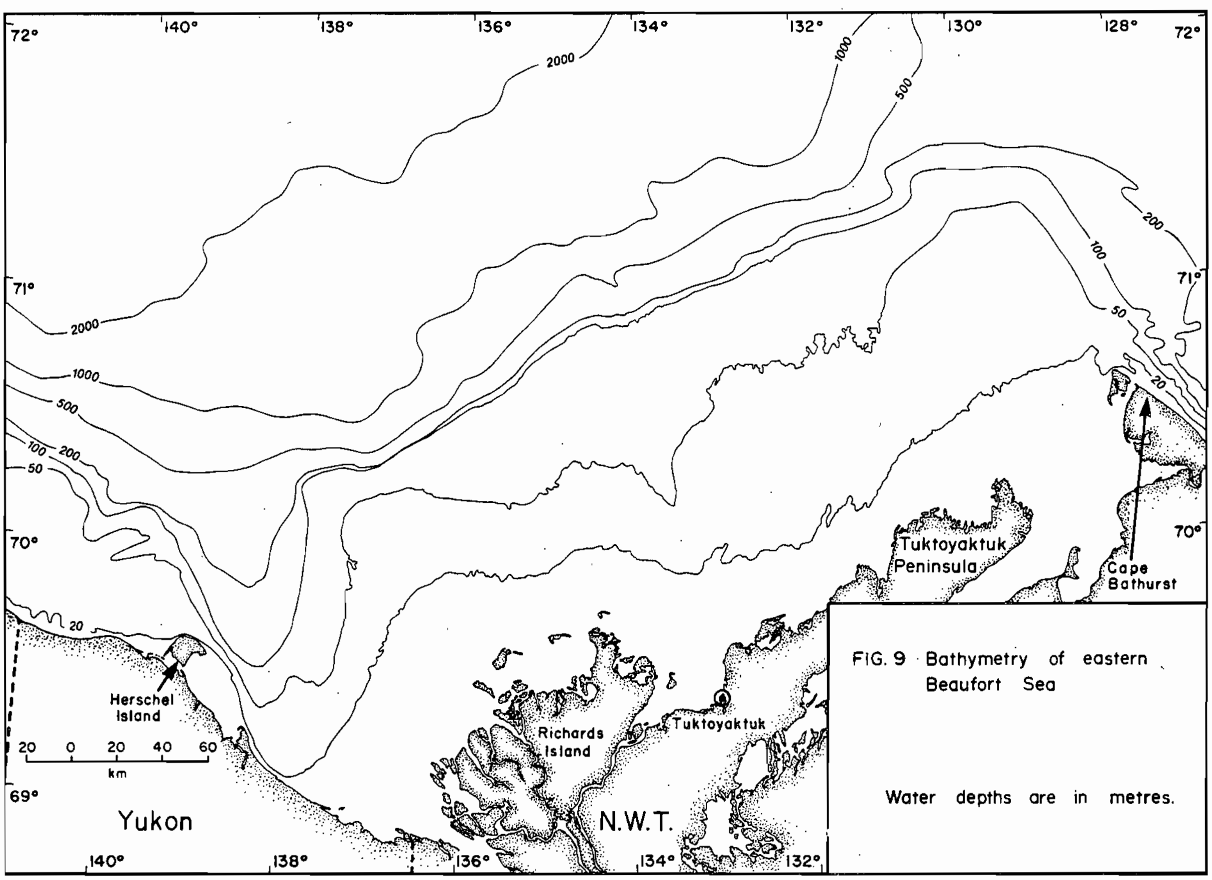


FIG. 9 Bathymetry of eastern Beaufort Sea

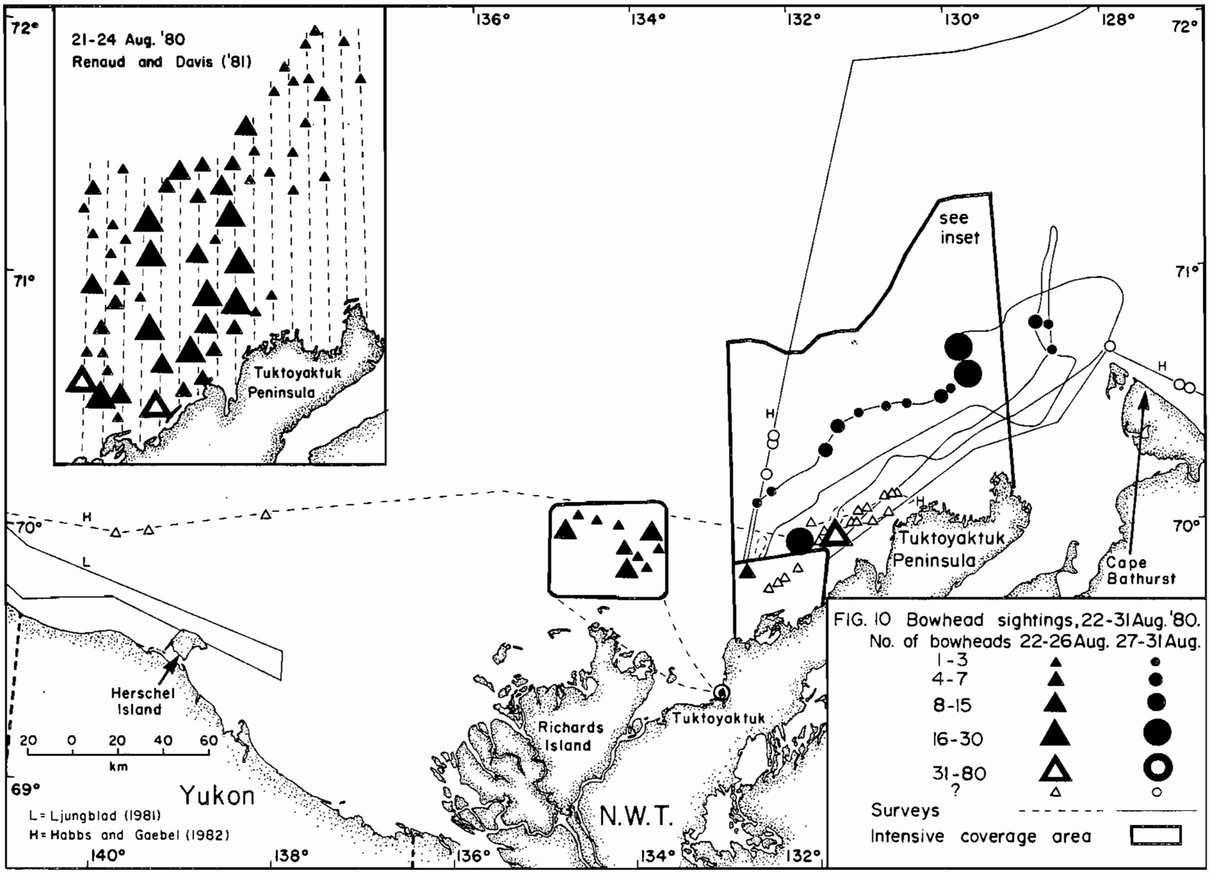


FIG. 10 Bowhead sightings, 22-31 Aug. '80.

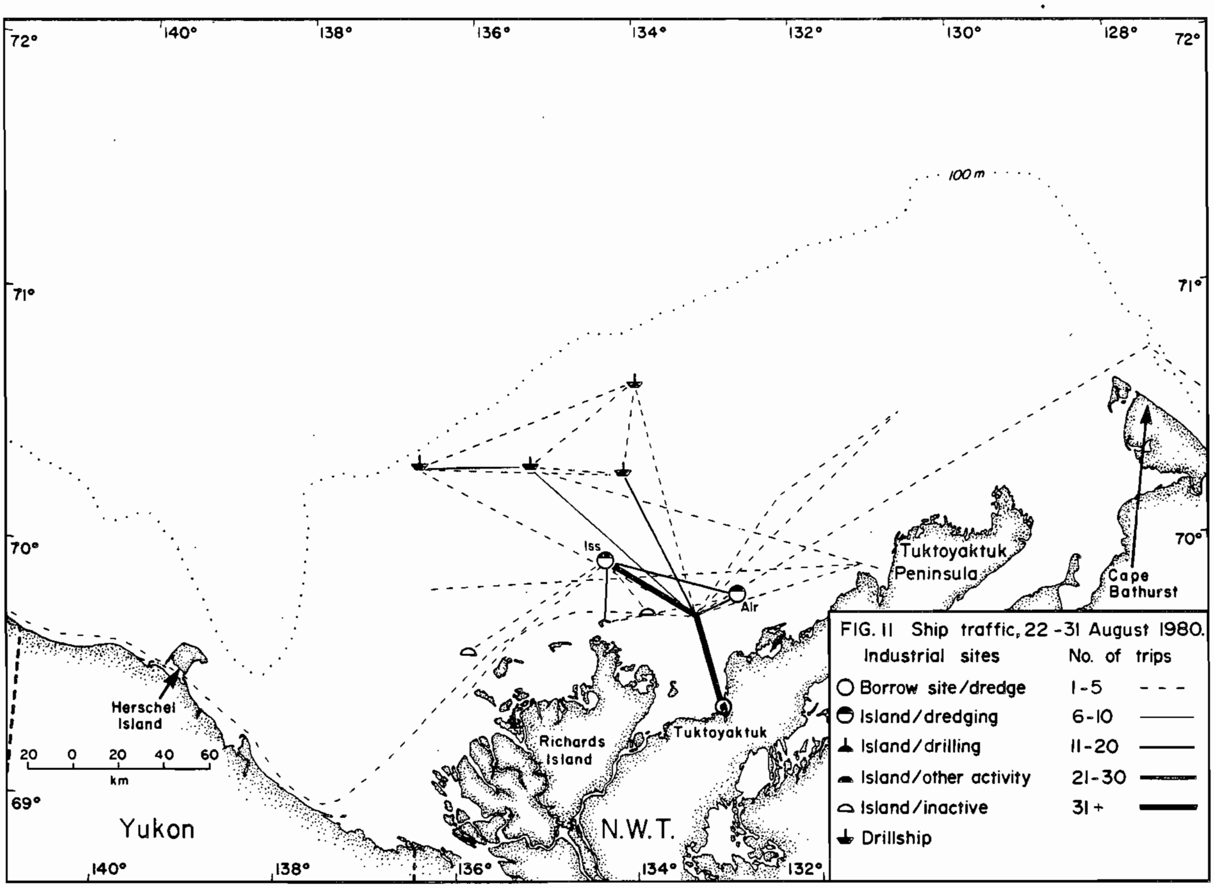


FIG. 11 Ship traffic, 22-31 August 1980.

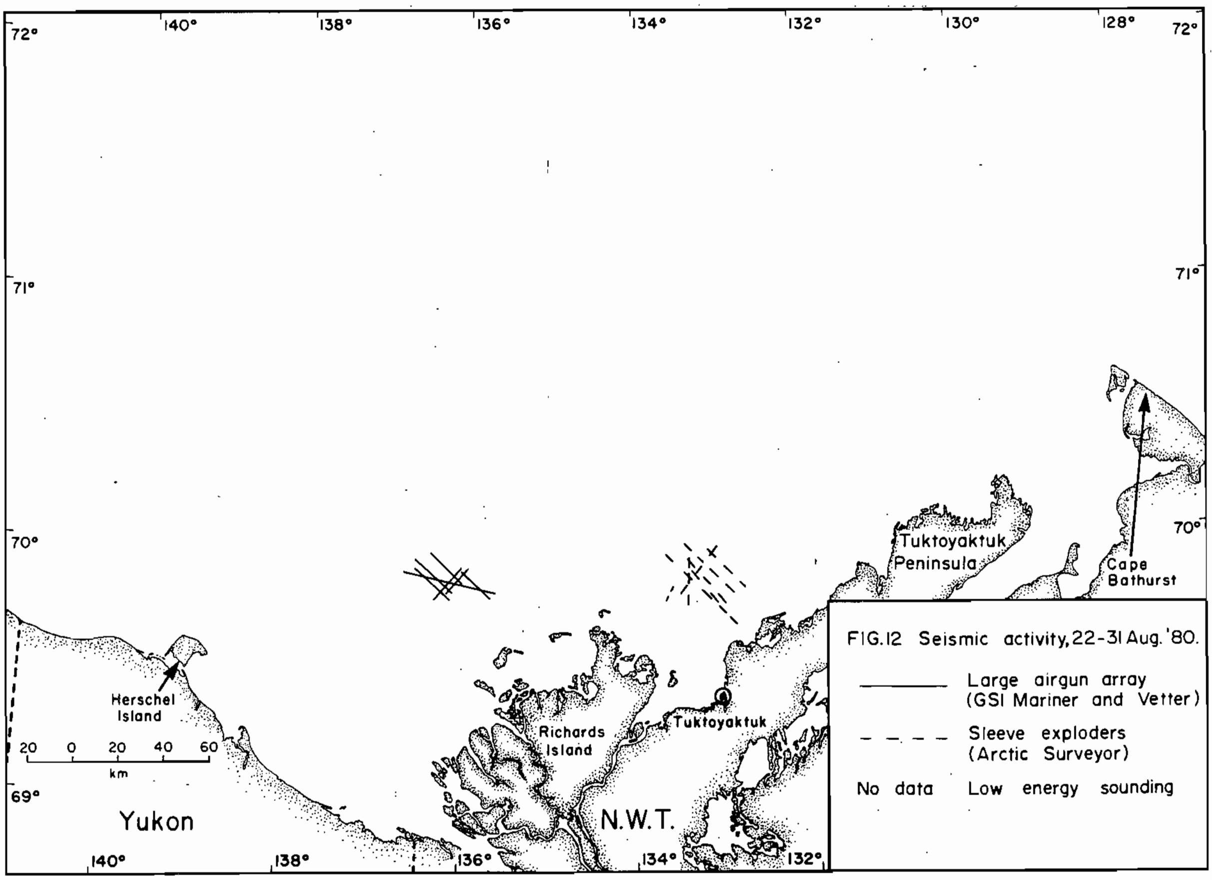


FIG. 12 Seismic activity, 22-31 Aug. '80.

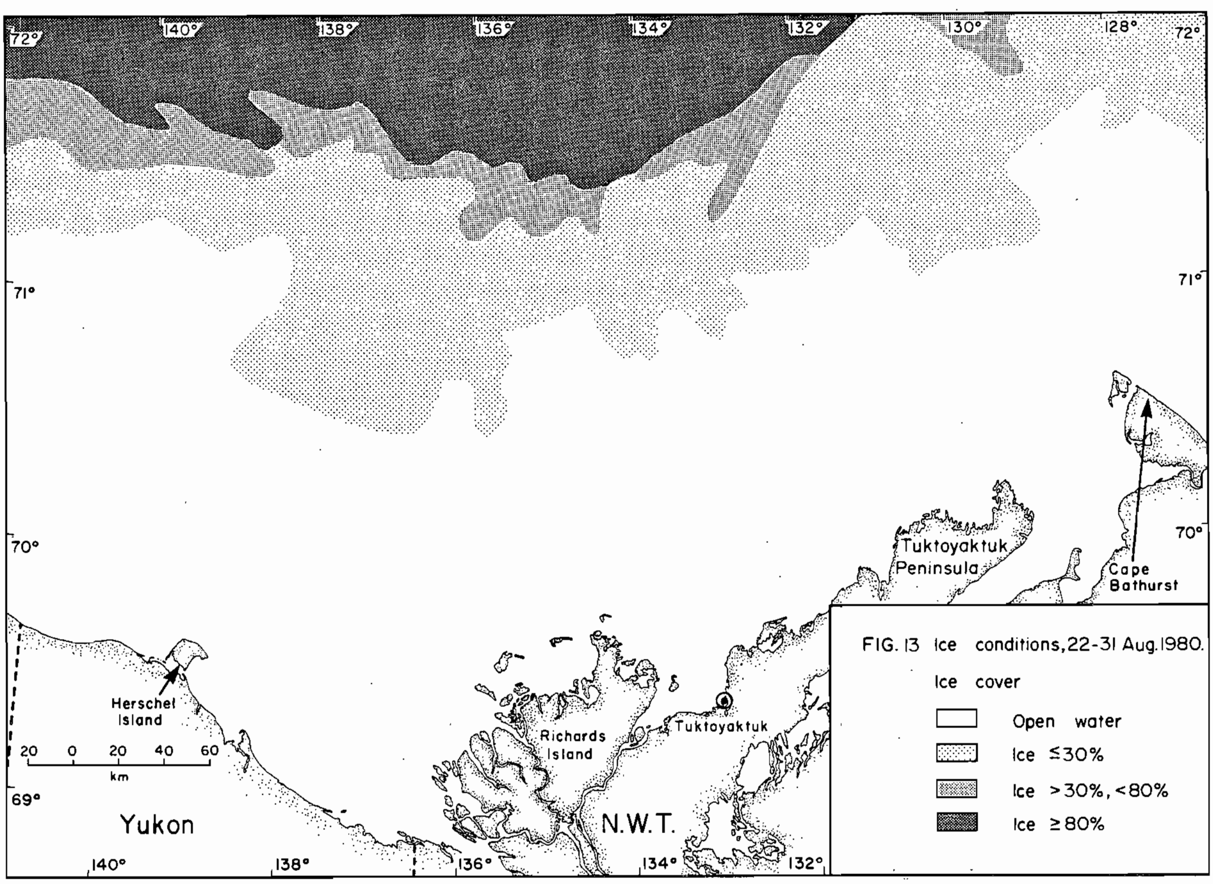


FIG. 13 Ice conditions, 22-31 Aug. 1980.

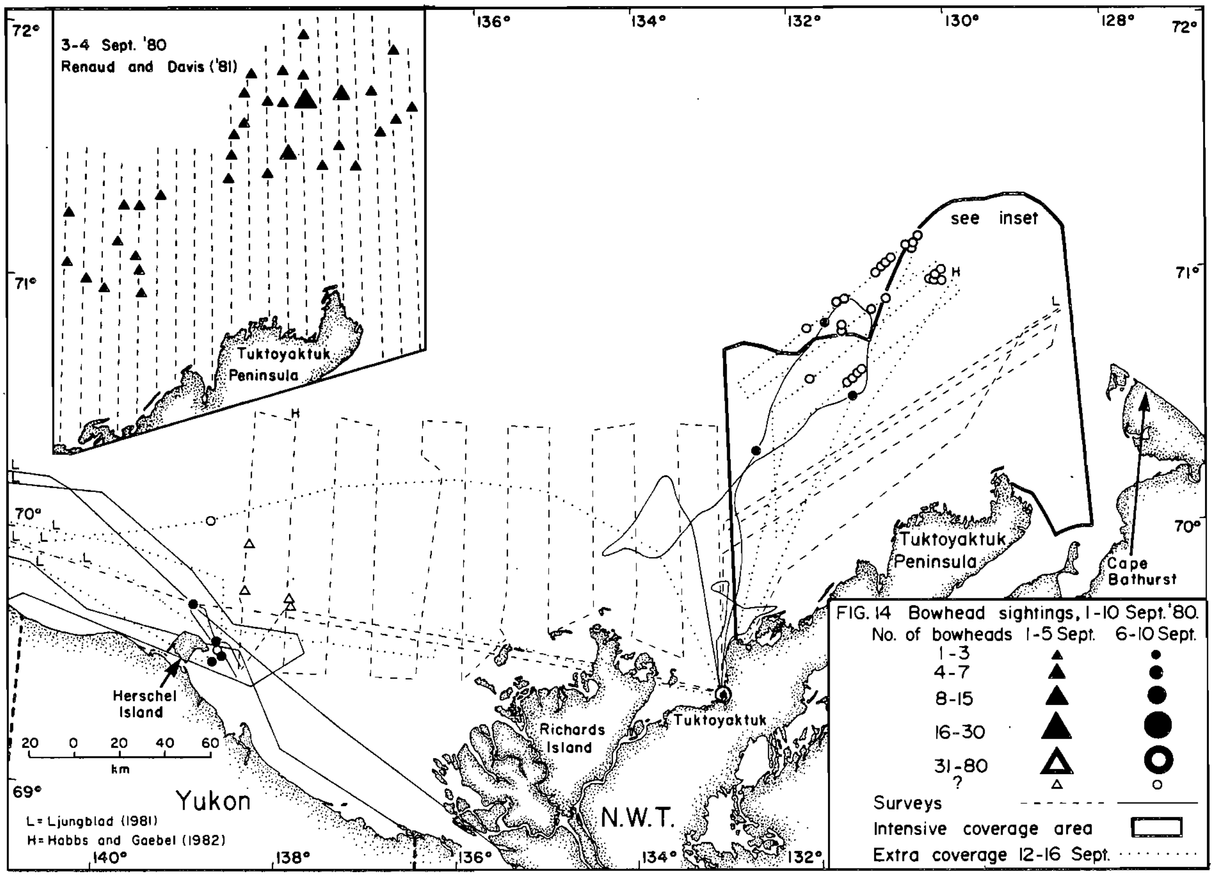


FIG. 14 Bowhead sightings, 1-10 Sept. '80.

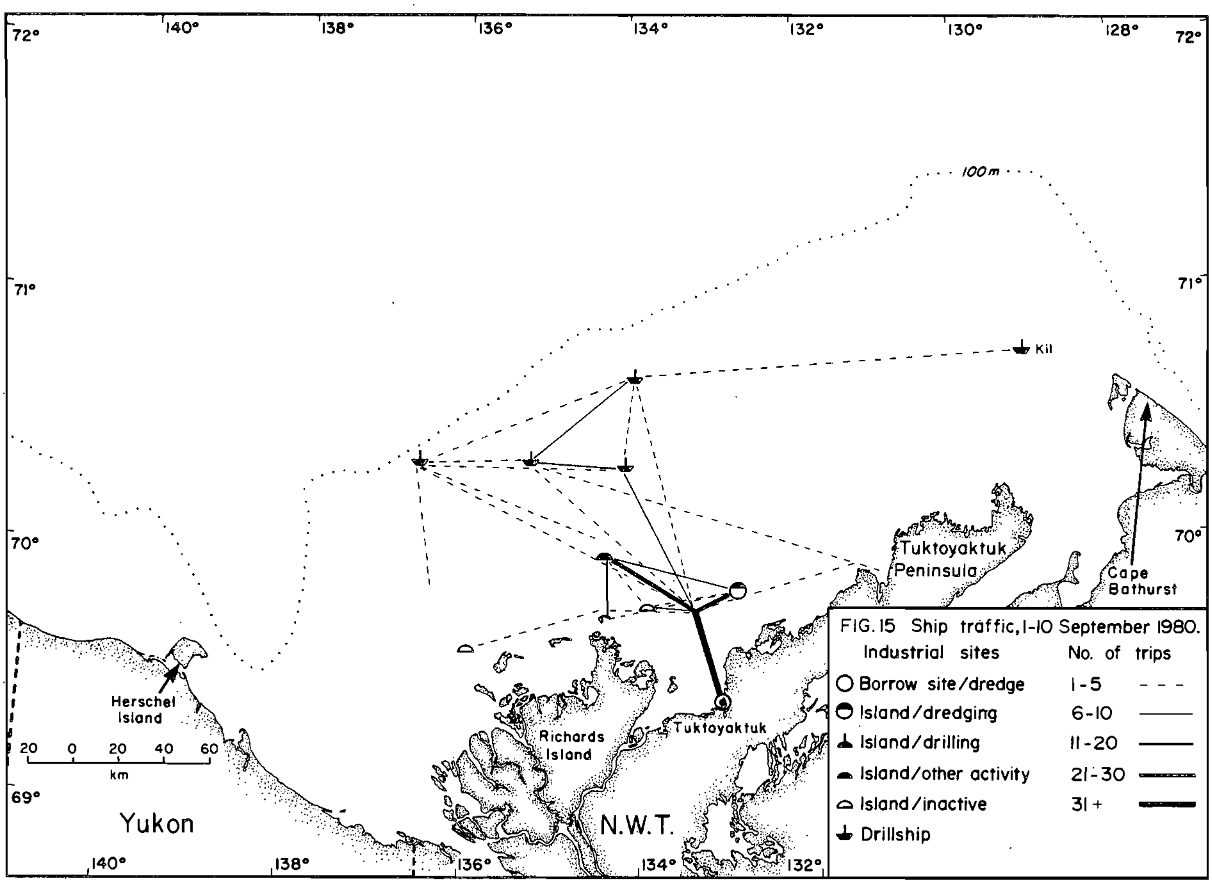


FIG. 15 Ship traffic, 1-10 September 1980.

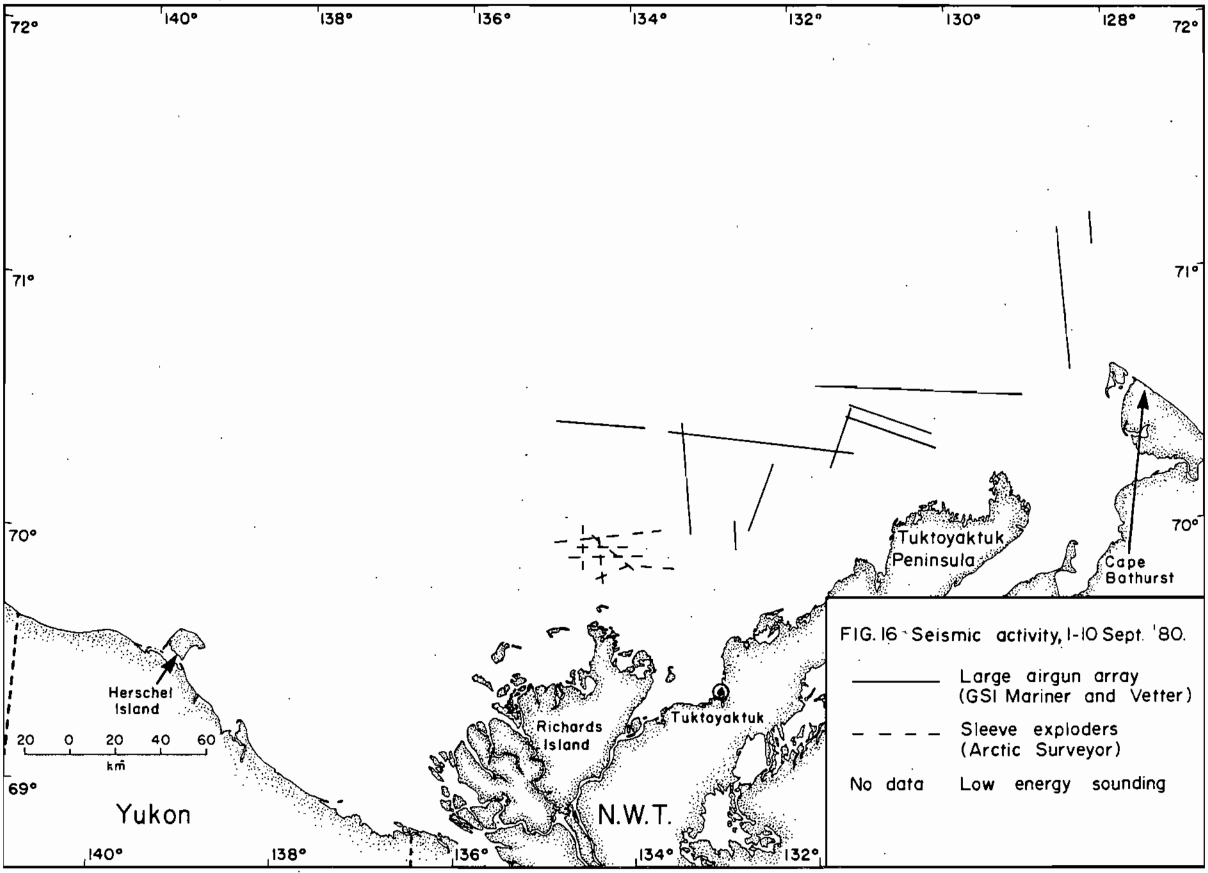


FIG. 16 - Seismic activity, 1-10 Sept. '80.

———	Large airgun array (GSI Mariner and Vetter)
– – – –	Sleeve exploders (Arctic Surveyor)
No data	Low energy sounding

Seismic exploration in early August was off the eastern part of the Mackenzie Delta and the Tuktoyaktuk Peninsula (Fig. 4). Seismic continued north of Tuktoyaktuk itself throughout August, with additional work farther west, around Tarsiut (Figs. 8, 12). In early September, seismic exploration occurred from the Issungnak area east to Cape Bathurst (Fig. 16). Additional seismic exploration at unknown locations and times occurred during the summer of 1980. We have no information about the amount or locations of low-energy sounding operations in 1980.

No specific information on helicopter activities was available for 1980. However, data from 1981-82 (see below) show that the general pattern of flights would follow that of vessel movements to and between the offshore industrial sites. Helicopters in use by the offshore operators in 1980 are listed in Table 1. All were of twin turbine engine design.

Table 1. Helicopters operating offshore from Tuktoyaktuk on behalf of the oil industry in the summers of 1980-82.

Manufacturer and Model	Length (m)*	Gross Wt (kg)*	# in Area 1980	# in Area 1981	# in Area 1982
Aerospatiale Super-Puma	18.7	8360	-	-	1
Bell 212	17.5	5080	2?	2?	3?
Bell 412	17.1	5270	-	-	1
MBB BO-105	11.7	2840	-	-	1
Sikorsky 61	22.3	9310	1	1	1
Sikorksy 76	16.0	4680	2	4	1
Total			5	7	8

* Data from Specifications, Aviat. Week & Space Technol. 118(11), 1983.

Bowhead Distribution, 1980

Bowheads were more numerous close to shore in 1980 than in the subsequent two years. Survey coverage of the more remote areas was less comprehensive in 1980, partly because researchers could easily locate bowheads close to shore. Considerable surveying was done inside the 50 m contour off the eastern Mackenzie Delta and Tuktoyaktuk (Tuk) Peninsula throughout August and early September. However, there was virtually no coverage of more westerly areas or areas of deeper water until early September. Because of the limited coverage, the large scale movement patterns of the whales in 1980 are not well documented. There was almost no ice in the relatively shallow areas surveyed during August (Figs. 5, 13).

The whereabouts of the bowheads during late July 1980 is not known. Survey coverage in this period was very limited and mostly in areas close to shore; the coverage is not mapped here. No bowheads were seen during a flight near Herschel Island on 21 July, and there was only one unconfirmed sighting during two flights off the Tuk Peninsula and Cape Bathurst on 22-23 July (Hobbs and Goebel 1982). None were seen during an intensive survey near the island construction operation at Issungnak on 24 July (Norton Fraker and Fraker 1981). The one offshore survey in late July was on 28 July from Prudhoe Bay northeast almost to Prince Patrick Island, then south off the west coast of Banks Island, and then ESE to Prudhoe Bay; no bowheads were seen (Ljungblad 1981).

In **early August 1980**, many bowheads were in the Issungnak area (Fig. 2). Industry personnel building Issungnak Island reported bowheads on 8 of 9 days from 2 to 10 August (Fraker et al. 1982), and Würsig et al. (1982) saw bowheads there from 3 August onward. Systematic surveys around Issungnak on 5, 9, 11 and 12 August all found many whales in that area. Many were within 5 km and a few within 1 km from the suction dredge and support vessels operating at Issungnak (Norton Fraker and Fraker 1981; Fraker et al. 1982). The whales were socializing, diving, and feeding in this area. There is no information about where these whales had been before they moved into the Issungnak area around the first of August.

During the same period, intensive surveys out to the 50 m contour along the whole length of the Tuk Peninsula showed that there were few whales in that more easterly area (Fig. 2).

There is almost no information about the occurrence of bowheads in areas more than 25 km north or west of Issungnak, but whales clearly were concentrated in the area of heaviest industrial activity. Seismic exploration was occurring both north of Issungnak and off the Tuk Peninsula; other forms of industrial activity were much more intense near Issungnak. Besides traffic in support of the construction operation at Issungnak, vessel and helicopter traffic to at least 3 of the 4 drillships passed through the area where bowheads were concentrated (Fig. 3).

In **mid August 1980**, bowheads were still numerous near Issungnak, but many bowheads appeared farther east off the Tuk Peninsula (Fig. 6). Within the 11-21 August period, most sightings near Issungnak were before 16 August (triangle symbols in Fig. 6), whereas all sightings off the Tuk Peninsula were on or after 14 August. Hobbs and Goebel (1982) reported many bowheads in waters <30 m deep off the Tuk Peninsula during six flights on 14-22 August. During flights on 19, 20 and 21 August, they saw 114, 157 and 245 bowheads, mostly in these shallow waters. Many whales were seen feeding in waters as shallow as 10 m (Würsig et al. 1982). Figure 9 shows the bathymetry of the area.

There were no aerial surveys far west of Issungnak during mid August, and only one flight far to the north. The latter detected no bowheads far offshore (Hobbs and Goebel 1982). Observers looking for bowheads were at King Point along the Yukon coast from 16 August to 13 September; they saw only one bowhead, on 18 August (Würsig et al. 1982).

During mid August, island construction and frequent vessel traffic continued around Issungnak; industrial activity was less intense off the Tuk Peninsula (Fig. 7). Seismic activity occurred between these two areas (Fig. 8), and some whales there were as close as 8 and 13 km from an active seismic ship on 20 and 21 August (Richardson et al. 1983b).

During **late August 1980**, large numbers of bowheads were off the Tuktoyaktuk Peninsula; densities near Issungnak were reduced from those in early August but still appreciable (Fraker et al. 1982). Based on a systematic survey on 21-24 August (Fig. 10, inset), Renaud and Davis (1981) conservatively estimated that 755 bowheads were present off the Tuk Peninsula within the 50 m contour. That estimate includes no allowance for whales below the surface and invisible as the survey craft passed over. More whales appeared to be moving east than west. Whale densities were significantly higher in the west than the east side of the area off the Tuk Peninsula on 21-24 August. However, some were found as far east as Cape Bathurst. Würsig et al. (1982) found many bowheads feeding at or near the surface off the Tuk Peninsula; others were socializing. Industrial activities were similar to those in mid August.

Hobbs and Goebel (1982) report no bowhead sightings far offshore during a flight northeast to Banks Island on 31 August, but 12 whales were seen in water about 50-250 m deep off the Yukon coast on 22 August (Fig. 10). Because of the lack of earlier flights west of Issungnak, it is unknown whether bowheads had been present off the Yukon coast earlier in August.

During **early September 1980**, survey coverage was more extensive. A systematic survey off the Tuk Peninsula on 3-4 September revealed only about 1/3 as many whales as on 21-24 August (Fig. 14, inset; Renaud and Davis 1981). The whales off the Tuk Peninsula also tended to be farther offshore than in late August; all were in at least 25 m of water. Most of the whales seen on 3-4 September were oriented to the SW or west (Renaud and Davis 1981). However on 12 September, the last day of surveys, bowheads were still present off the Tuk Peninsula near the 50 m depth contour (Hobbs and Goebel 1982).

No bowheads were seen during aerial surveys around Issungnak or elsewhere off the Mackenzie Delta in early September. One was reported by industry personnel at Issungnak on 11 September (Fraker et al. 1982).

Bowheads were present farther west, near Herschel Island, in early September (Fig. 14). In addition to the sightings during aerial surveys (Fig. 14), observers on the east tip of Herschel Island saw bowheads within a few kilometres from shore on 3-11 September; none had been seen there from 19 August to 2 September (Würsig et al. 1982). The last September coverage was on 16 September, when Ljungblad (1981) saw three bowheads just east of Herschel Island.

Most bowheads seen in early September were well away from the areas of offshore industrial activity. However, some of those off the Tuk Peninsula were near seismic lines (Fig. 14 vs. 16).

In the Alaskan Beaufort Sea, the first sighting during autumn was on 4 September east of Barter Island (Ljungblad 1981). Bowheads became numerous there by 14 September, and the last sighting in the Alaskan Beaufort was a pilot's report on 17 October (Ljungblad 1981). On 21 and 24 October Ljungblad flew east as far as Herschel Island and saw no bowheads.

Bowhead Distribution and Industrial Activities in 1981

The information for 1981 appears in Figures 17 to 38. The period 22 July to 10 September is considered.

Industrial Activity, 1981

The level of industrial activities during 1981 was higher than in 1980 but somewhat lower than in 1982. Esso and Dome intensified their offshore operations somewhat, and Gulf began offshore operations after an absence of several years. Most of Gulf's work was subcontracted to Dome, but Gulf operated two sounding vessels. The most significant increase in activity in 1981 was the arrival of two hopper dredges, which operated widely throughout the study area. Those dredges and other means were used to begin construction of islands in deeper water than previously--in 23 m at Tarsiut and 31 m at Uviluk (Fig. 22).

All drilling during the 1981 study period was from four drillships. Three ships remained at specific wellsites throughout the period and the other was at the easternmost wellsite until 5 September (Fig. 18). The latter drillship was at Orvilruk from 7 September onward (Fig. 36). Drilling at Issungnak artificial island was completed before the study period, but the island was still occupied and serviced by vessels and helicopters during August.

During 1981, two suction dredges and two hopper dredges were active in the study area. The suction dredge 'Beaver Mackenzie' alternated between two island construction sites NW and north of Tuktoyaktuk, Itiyok and Alerk, from 20 July to 6 September (Fig. 18). The other suction dredge, 'Aquarius', dredged at the South Tarsiut borrow site until 12 August; barges hauled the material to the Tarsiut island construction site (Fig. 18). Thereafter 'Aquarius' dredged in McKinley Bay. The two hopper dredges, 'Hendrik Zanen' and 'Geopotes X', travelled widely throughout the study period. They dredged at Herschel Island, South Tarsiut, Ukalerk, Uviluk and Banks Island, and brought the material to the Tarsiut and Uviluk island construction sites. The sites active in each 10-d period are shown on Figures 18, 22, 26, 32 and 36, and the movements of the hopper dredges are included with other vessel traffic on those maps.

Most vessel movements were again in support of the island building or drilling activities. Dome used 8 supply ships, an icebreaker, 5 tug-barge combinations, and 7 other vessels (J. Ward, Dome, pers. comm.). Esso used 7 tugs and 11 barges, 3 barge camps, and 4 crew boats (M. Psutka, Esso, pers. comm.). Vessel traffic occurred over a wider area in 1981 than 1980, partly because the newly arrived hopper dredges operated west to Herschel Island and northeast to Banks Island. There was additional traffic to the west because the caissons to be used to construct Tarsiut were barged around Alaska to Herschel Island and assembled there in late summer. At least four new vessels arrived in the Canadian Beaufort via Alaska this summer. Also, there was vessel traffic to support the one drillship that operated far to the east in 1981. NTCL vessels delivering supplies made several round trips from Tuktoyaktuk to Prudhoe Bay and to eastern locations. All clean-up operations at abandoned islands were in shallow water in July.

Seismic exploration occurred over wide areas of the eastern Beaufort Sea in 1981. At least three seismic ships with high-energy sources were operating in the area. They operated off the Mackenzie Delta and Yukon coast in late July; off the Mackenzie Delta in early August; from the Delta to Cape Bathurst in mid and late August; and off the Delta, Tuktoyaktuk, and the western Yukon in early September (Figs. 19, 23, 27, 33, 37). We understand that some additional seismic lines besides those on the maps were shot in August 1981.

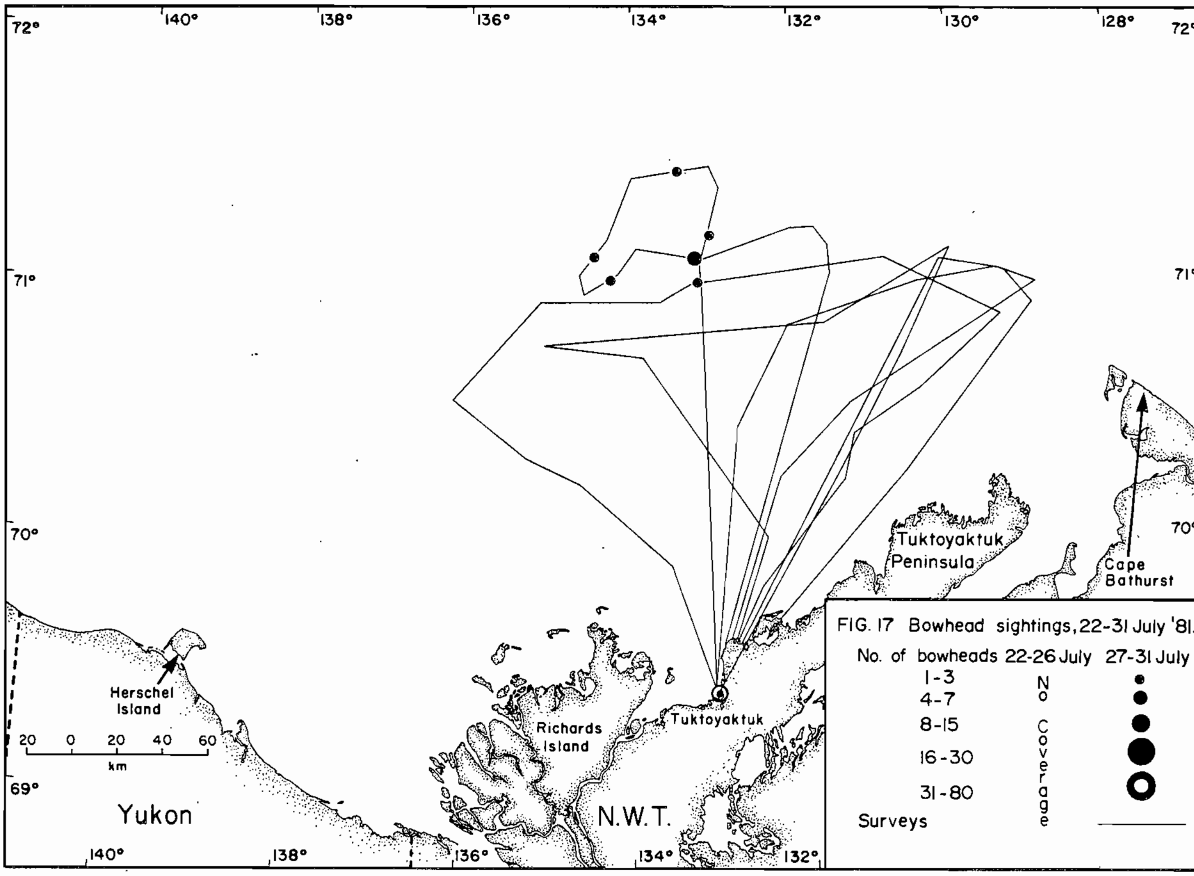


FIG. 17 Bowhead sightings, 22-31 July '81.

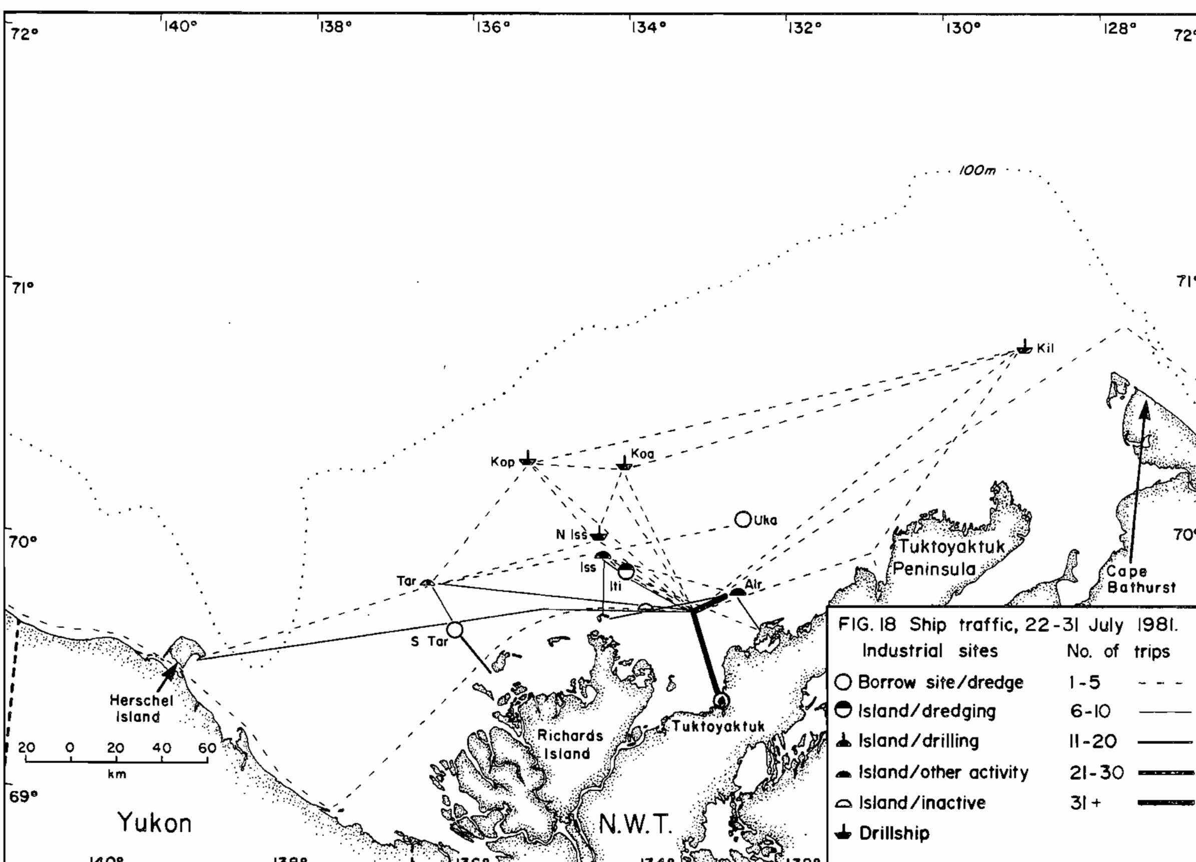
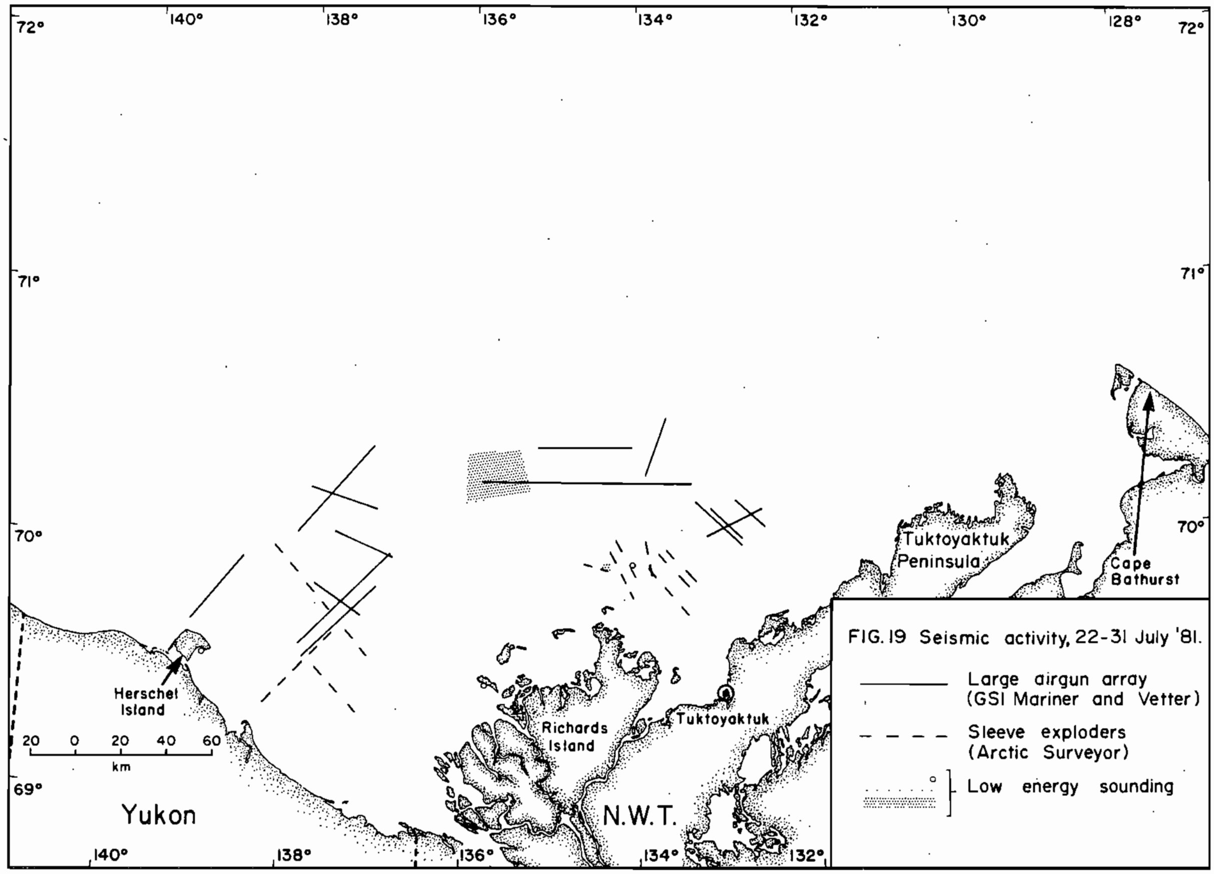
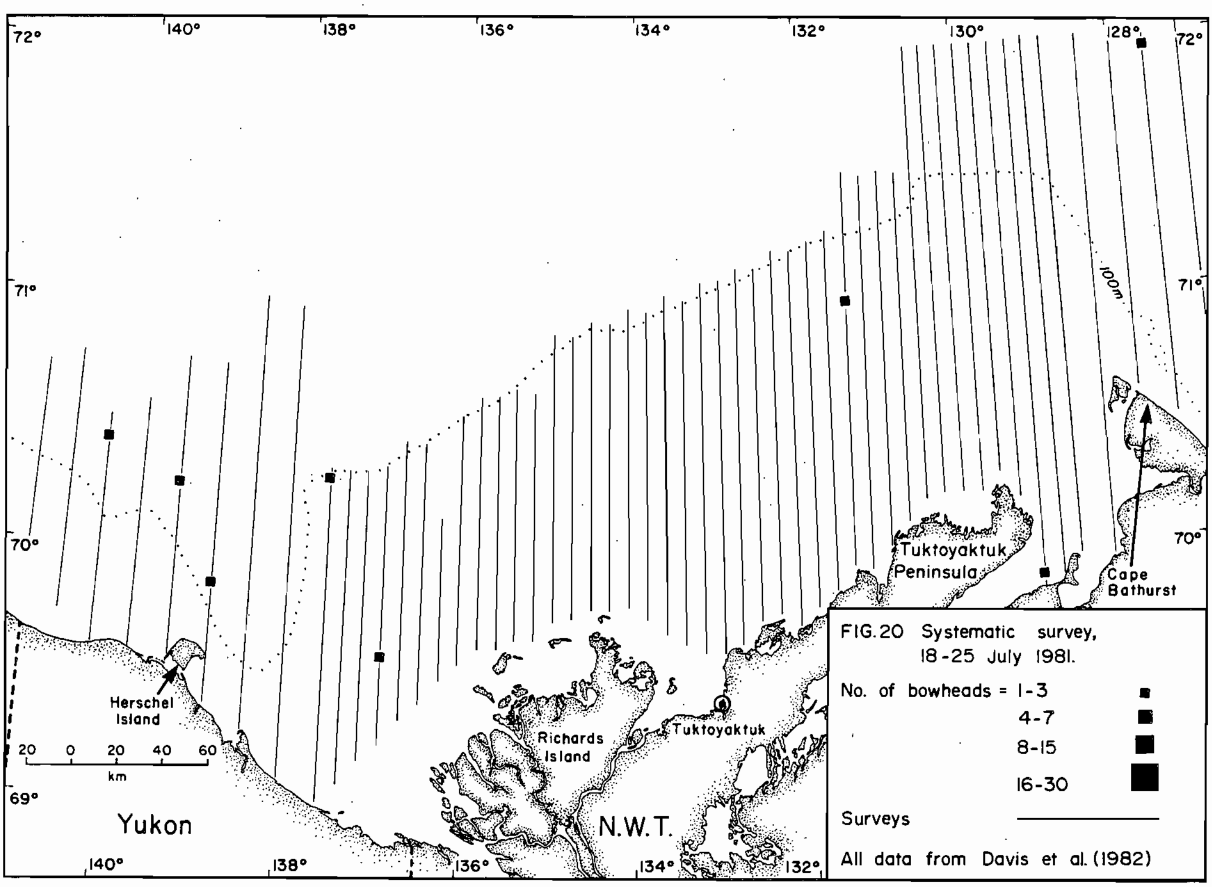


FIG. 18 Ship traffic, 22-31 July 1981.


72°
140°
138°
136°
134°
132°
130°
128°
71°
70°
69°
Tuktoyaktuk
Peninsula
Cape
Bathurst
Herschel
Island
20 0 20 40 60
km
Richards
Island
Tuktoyaktuk
Yukon
N.W.T.
FIG. 19 Seismic activity, 22-31 July '81.
Large airgun array
(GSI Mariner and Vetter)
Sleeve exploders
(Arctic Surveyor)
Low energy sounding


72°
140°
138°
136°
134°
132°
130°
128°
71°
70°
69°
100m
Tuktoyaktuk
Peninsula
Cape
Bathurst
Herschel
Island
20 0 20 40 60
km
Richards
Island
Tuktoyaktuk
Yukon
N.W.T.
FIG. 20 Systematic survey,
18-25 July 1981.
No. of bowheads = 1-3
4-7
8-15
16-30
Surveys
All data from Davis et al. (1982)

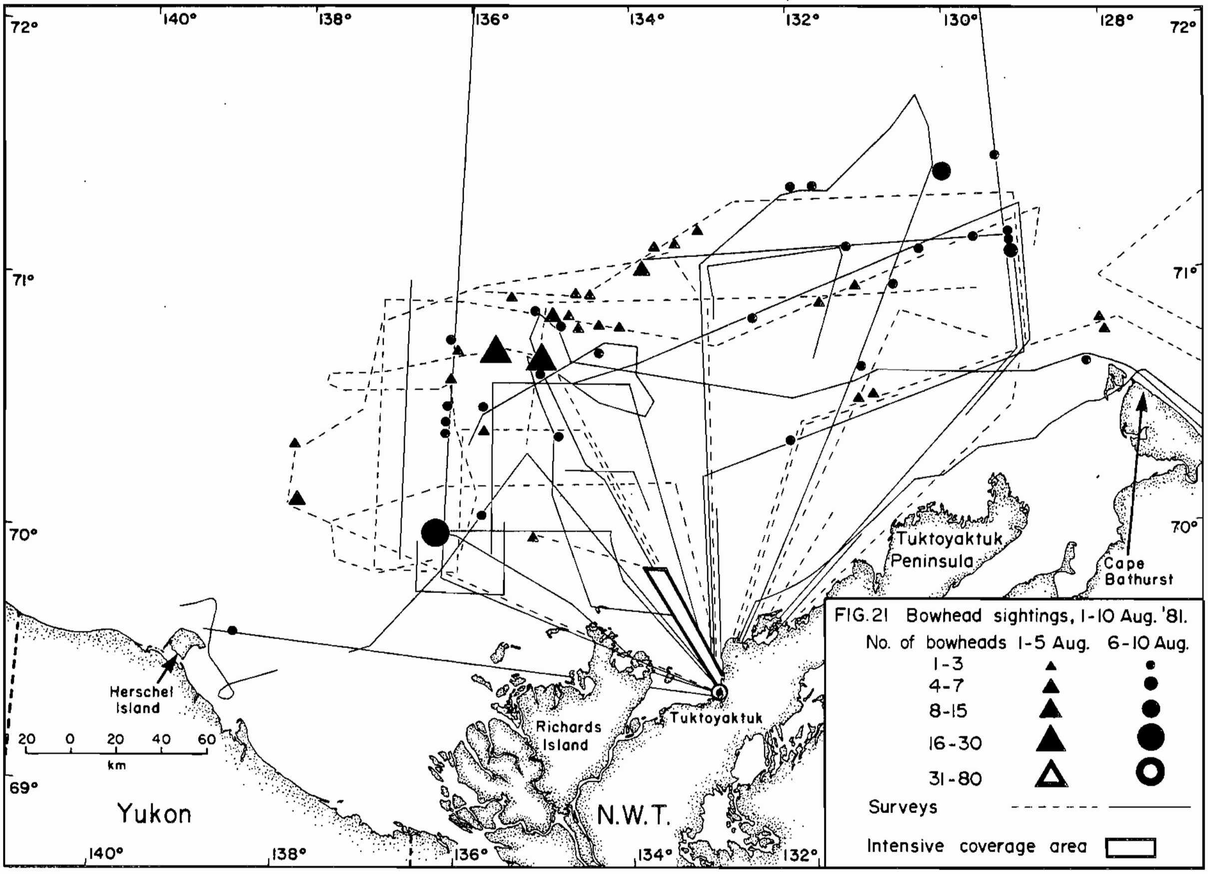


FIG.21 Bowhead sightings, 1-10 Aug. '81.

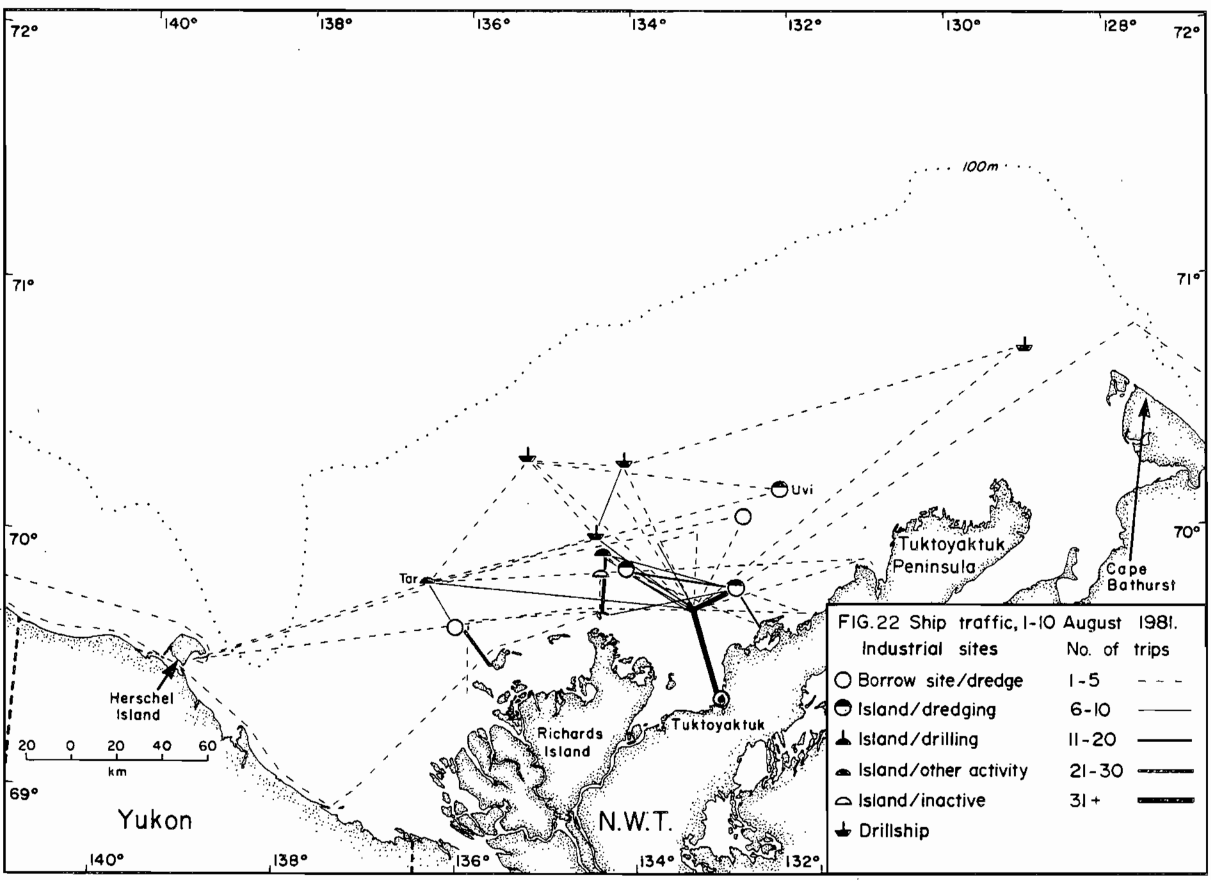


FIG.22 Ship traffic, 1-10 August 1981.

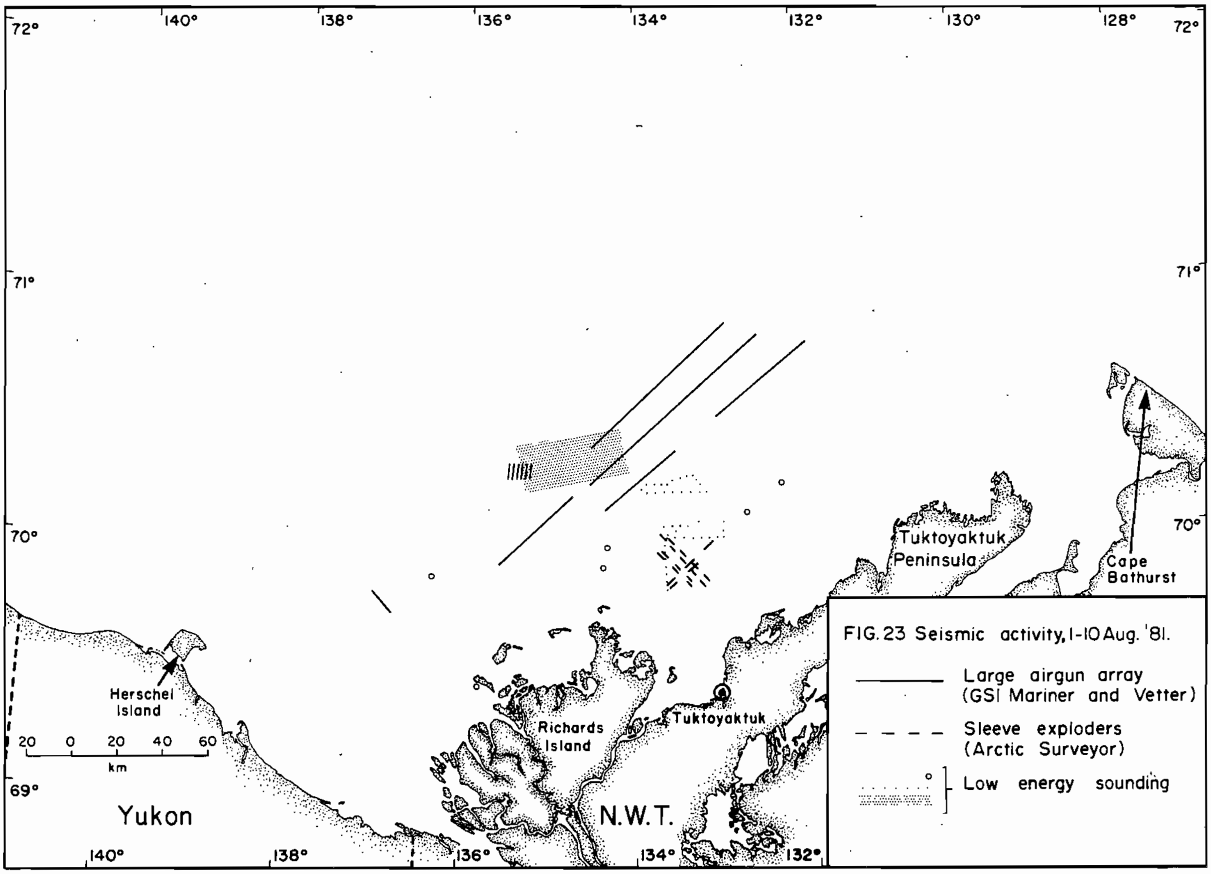


FIG. 23 Seismic activity, 1-10 Aug. '81.

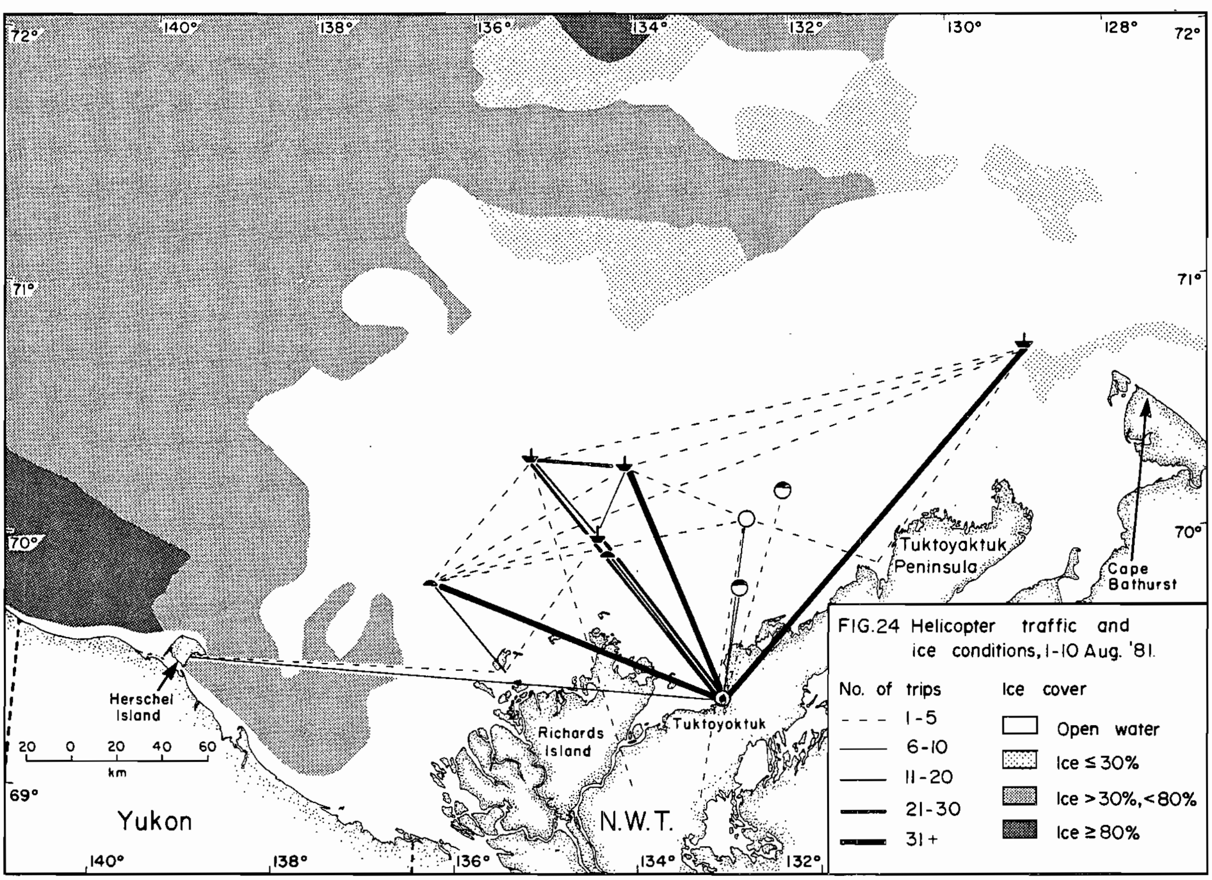


FIG. 24 Helicopter traffic and ice conditions, 1-10 Aug. '81.

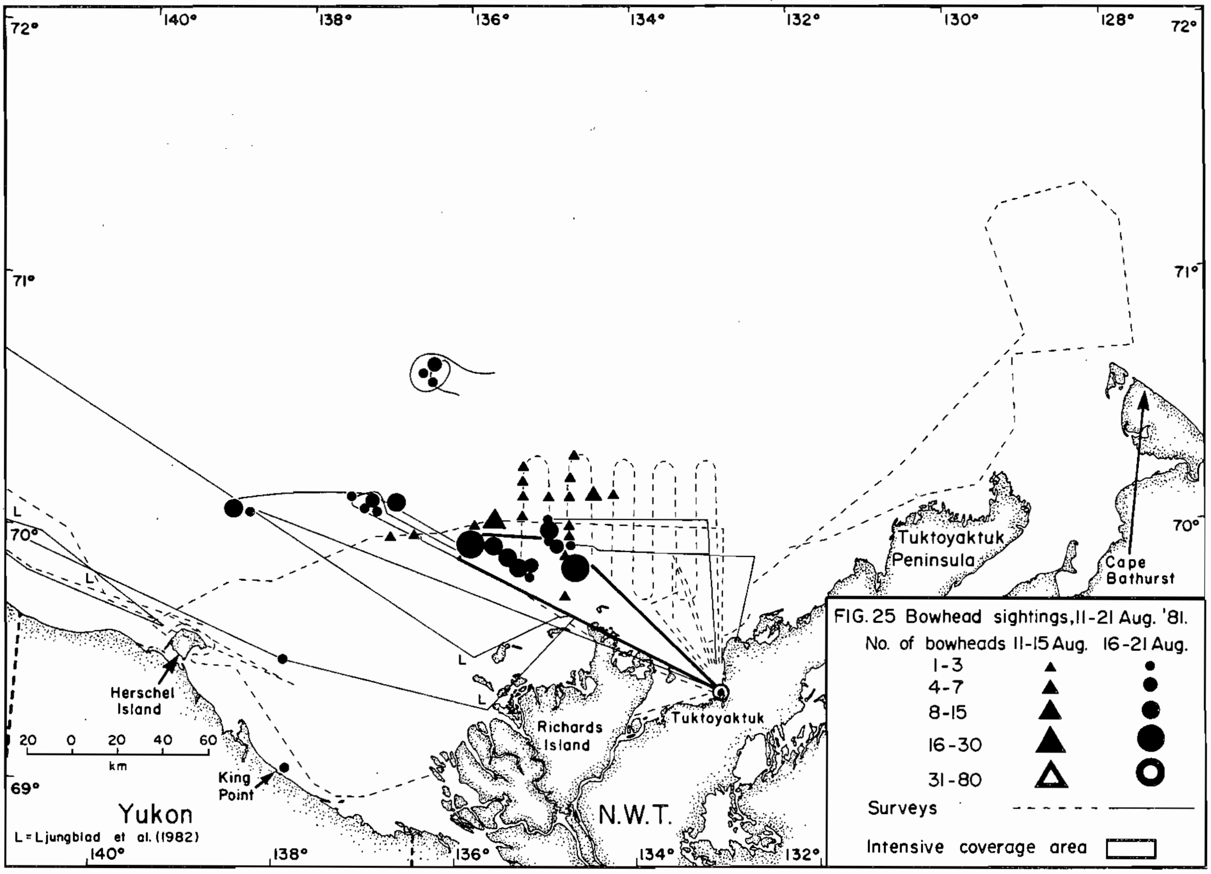


FIG. 25 Bowhead sightings, 11-21 Aug. '81.

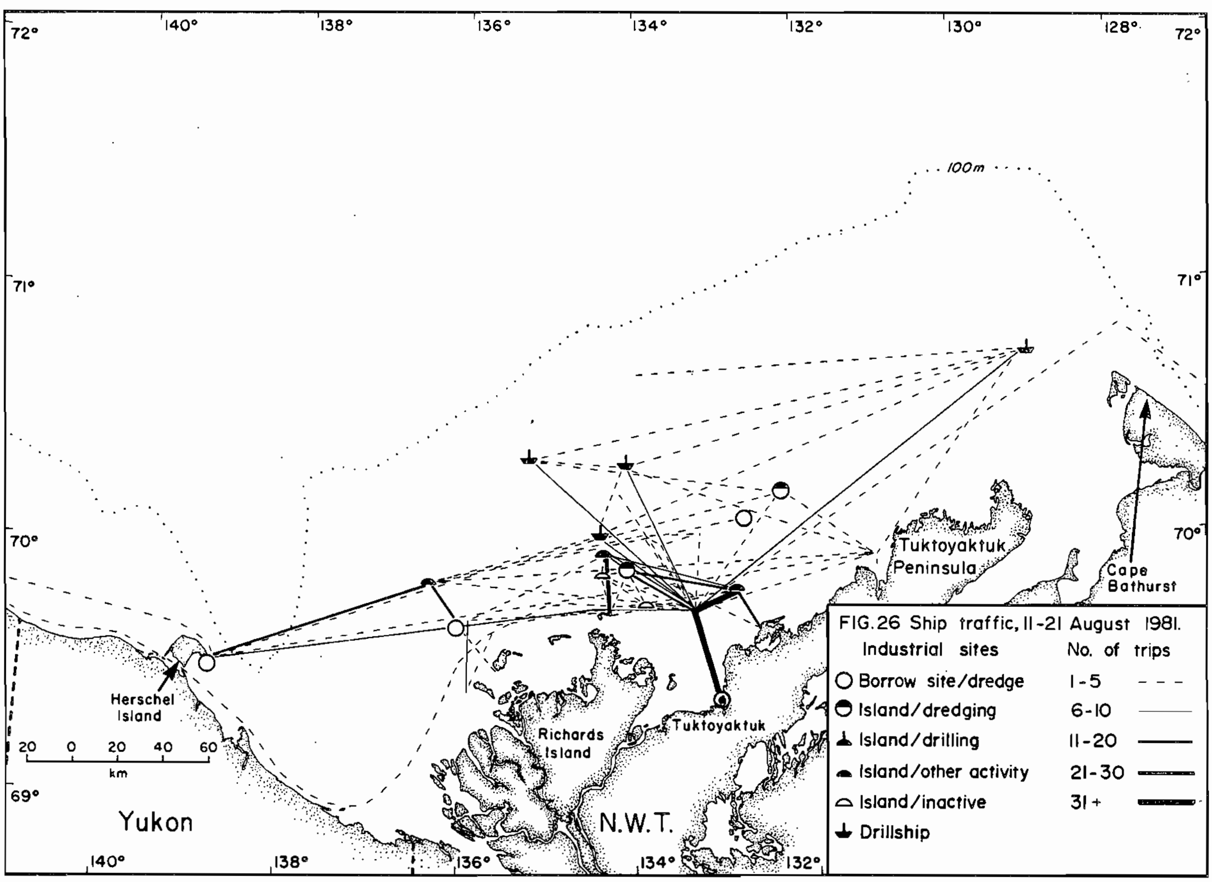


FIG. 26 Ship traffic, 11-21 August 1981.

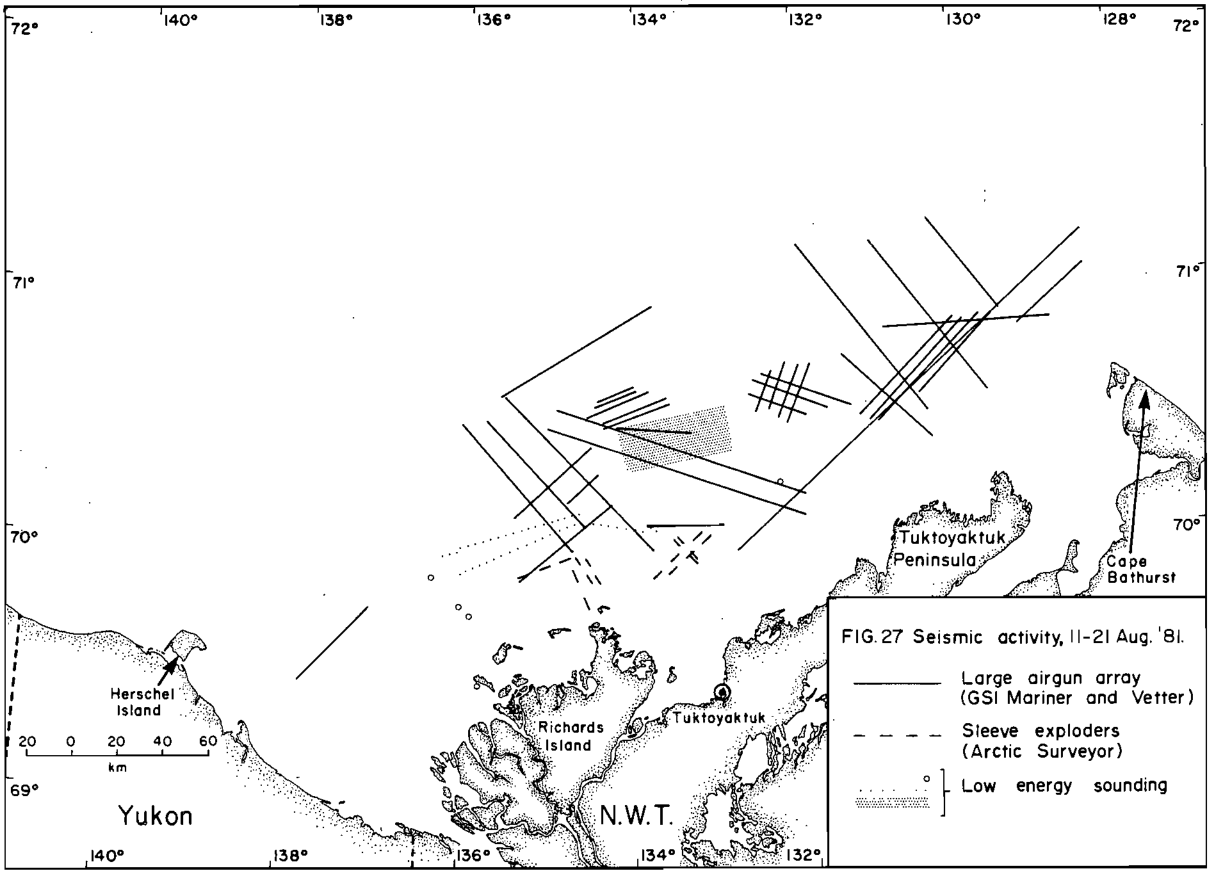


FIG. 27 Seismic activity, 11-21 Aug. '81.

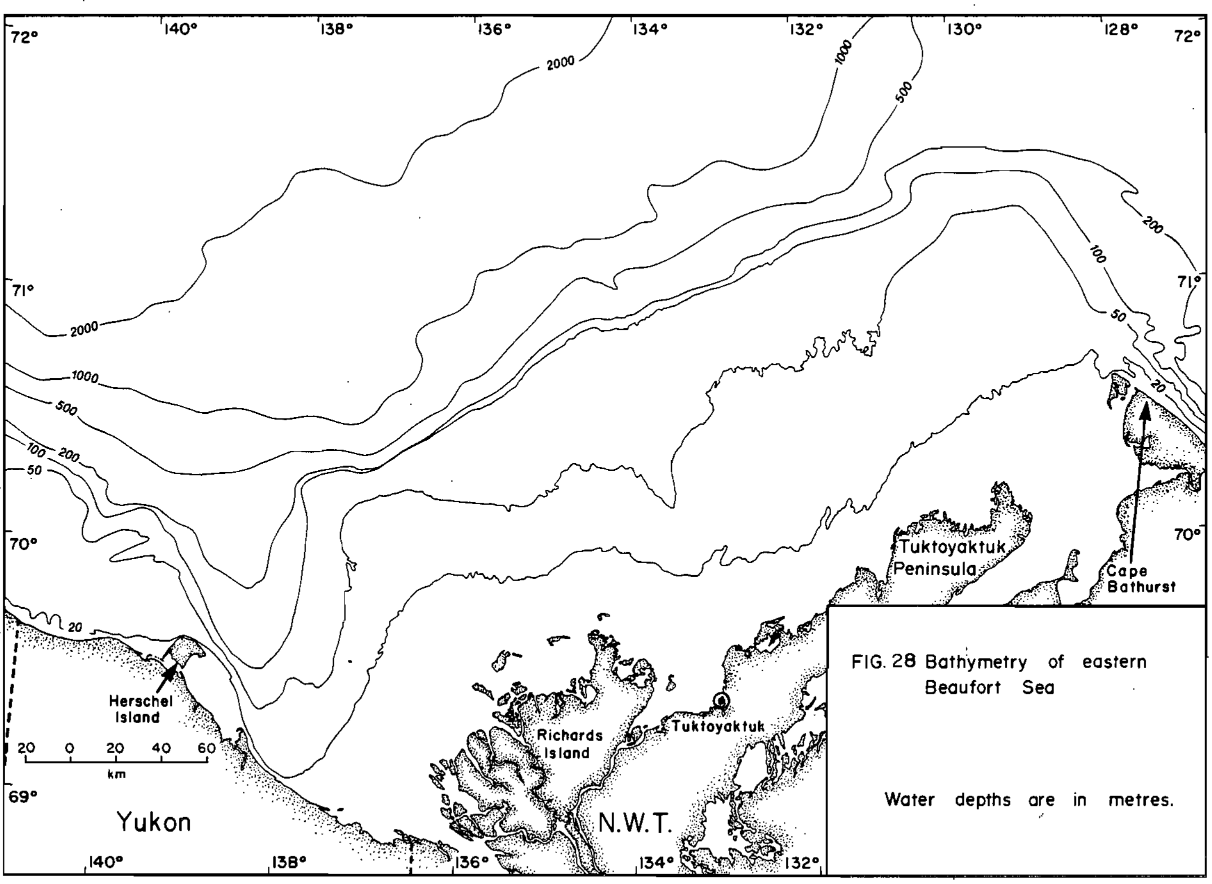


FIG. 28 Bathymetry of eastern Beaufort Sea

Water depths are in metres.

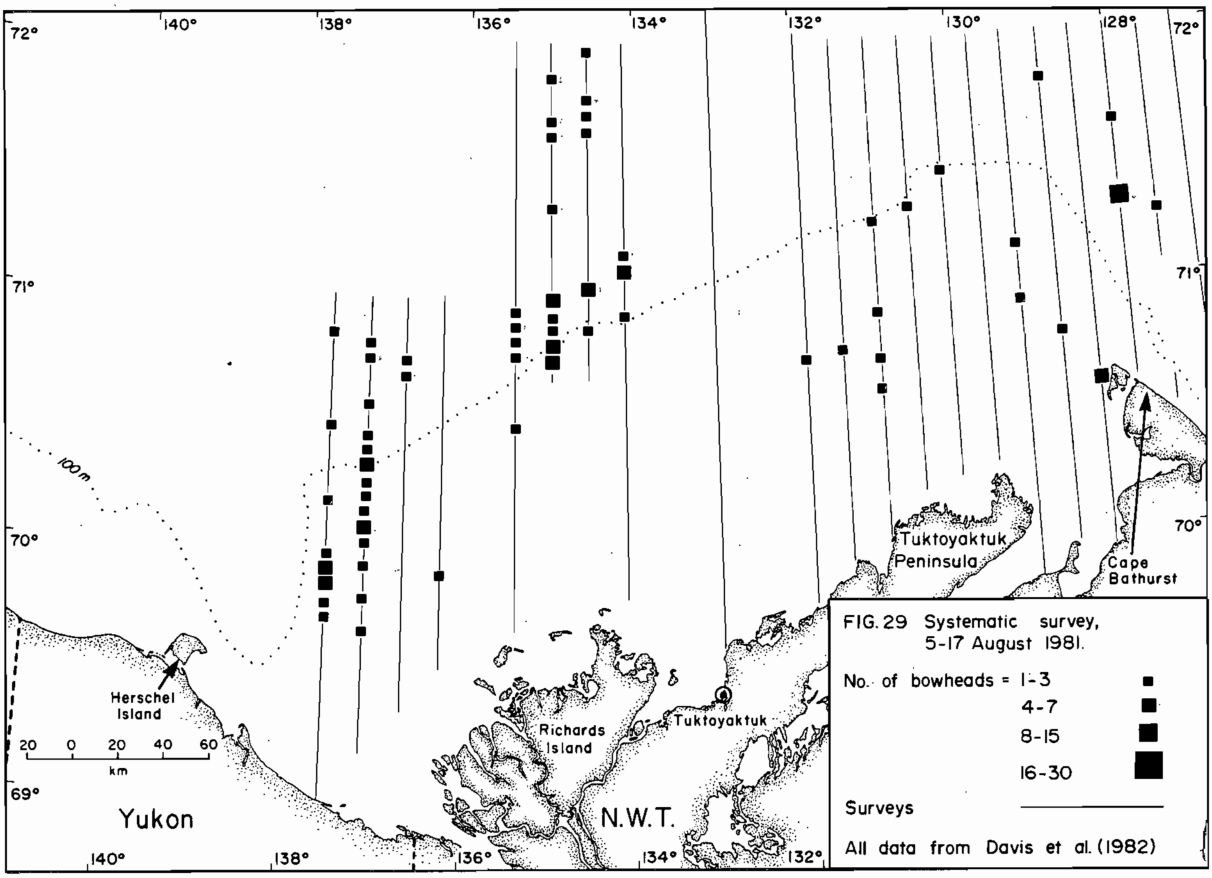


FIG. 29 Systematic survey, 5-17 August 1981.

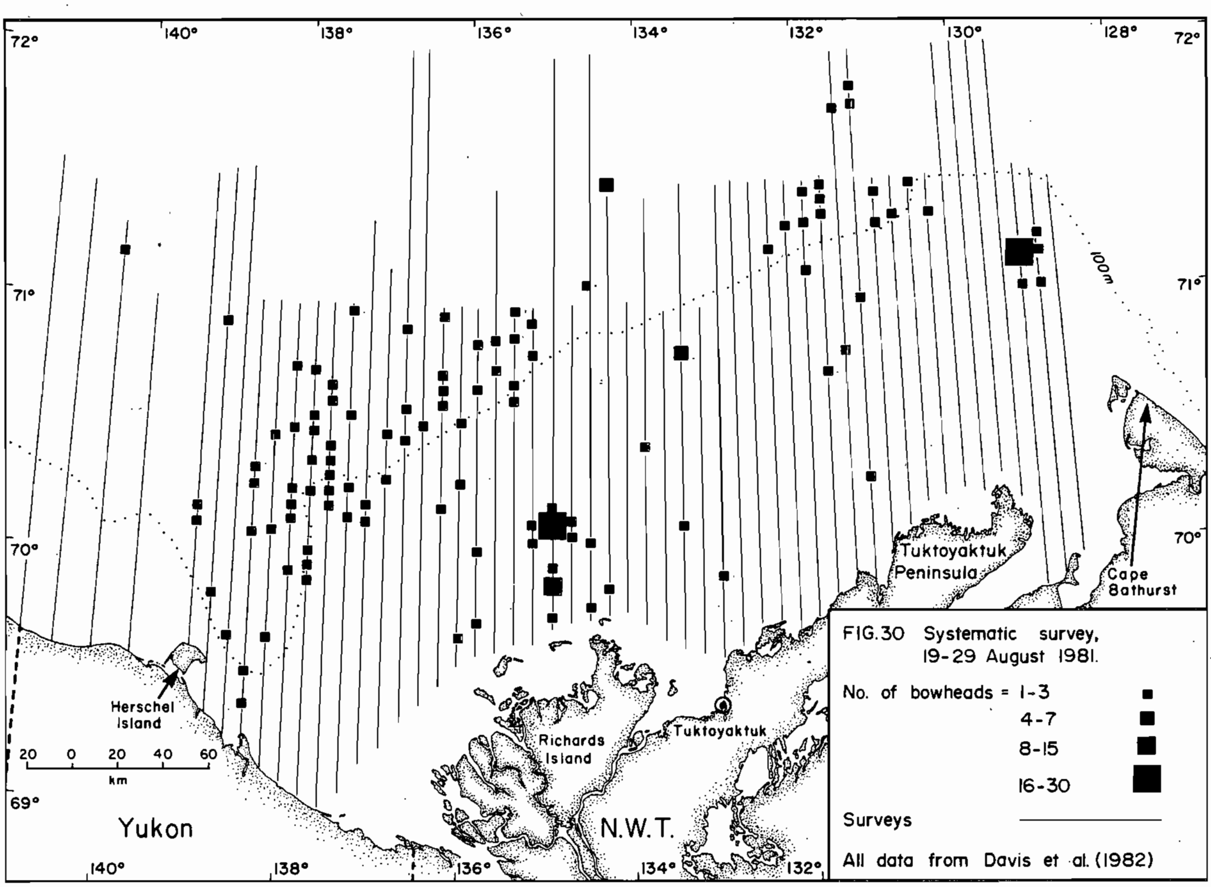
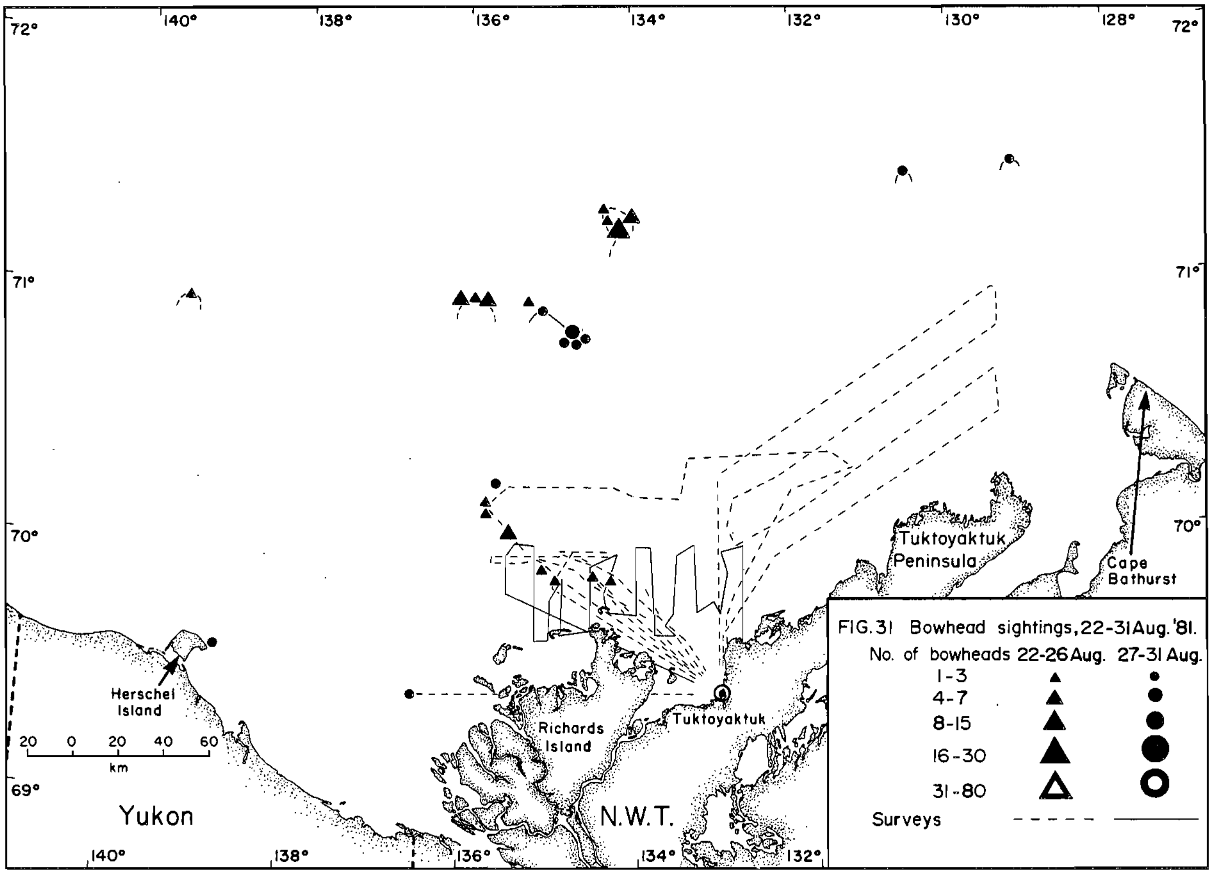
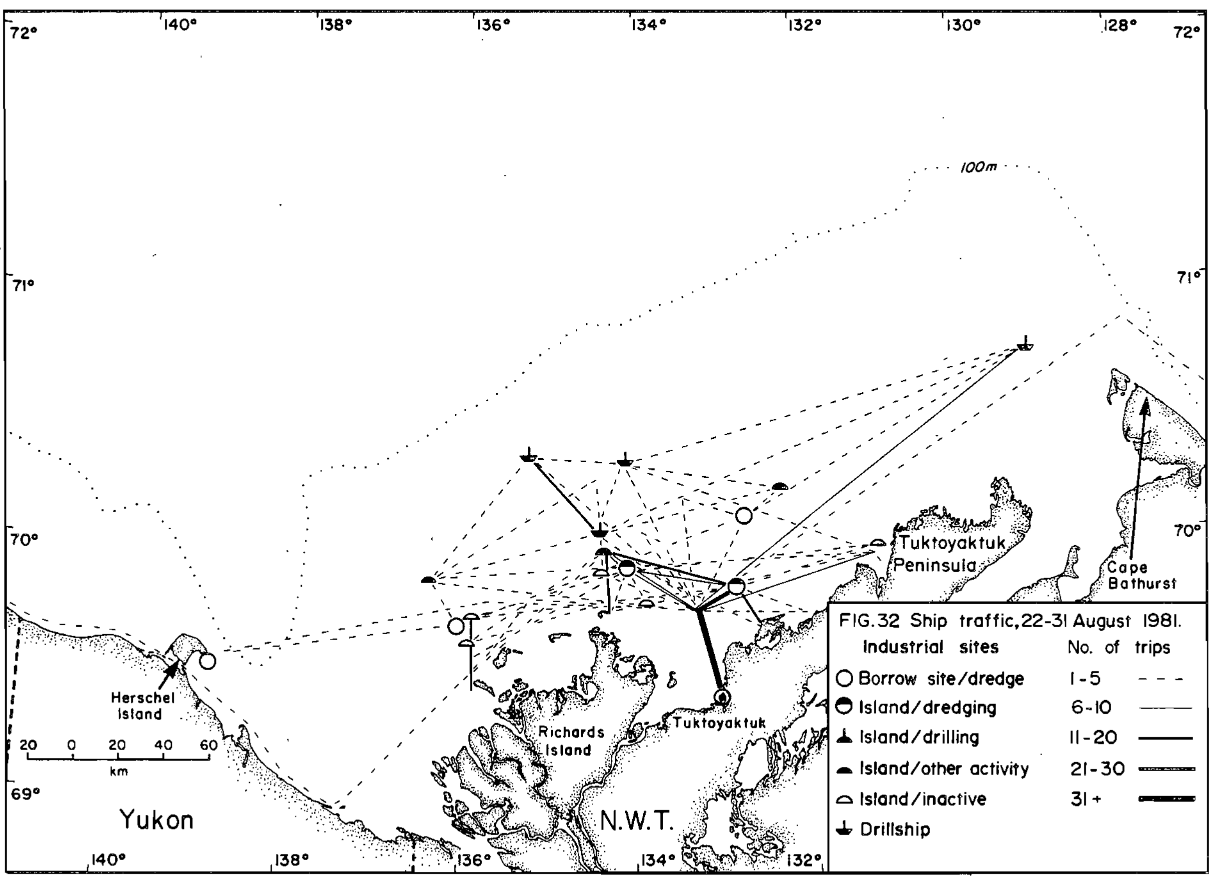


FIG. 30 Systematic survey, 19-29 August 1981.


72°
140°
138°
136°
134°
132°
130°
128°
71°
70°
69°
Tuktoyaktuk Peninsula
Cape Bathurst
Herschel Island
Richards Island
Tuktoyaktuk
Yukon
N.W.T.
20 0 20 40 60
km
FIG. 31 Bowhead sightings, 22-31 Aug. '81.
No. of bowheads 22-26 Aug. 27-31 Aug.
1-3
4-7
8-15
16-30
31-80
Surveys


72°
140°
138°
136°
134°
132°
130°
128°
71°
70°
69°
100m
Tuktoyaktuk Peninsula
Cape Bathurst
Herschel Island
Richards Island
Tuktoyaktuk
Yukon
N.W.T.
20 0 20 40 60
km
FIG. 32 Ship traffic, 22-31 August 1981.
Industrial sites
No. of trips
Borrow site/dredge
Island/dredging
Island/drilling
Island/other activity
Island/inactive
Drillship
1-5
6-10
11-20
21-30
31+

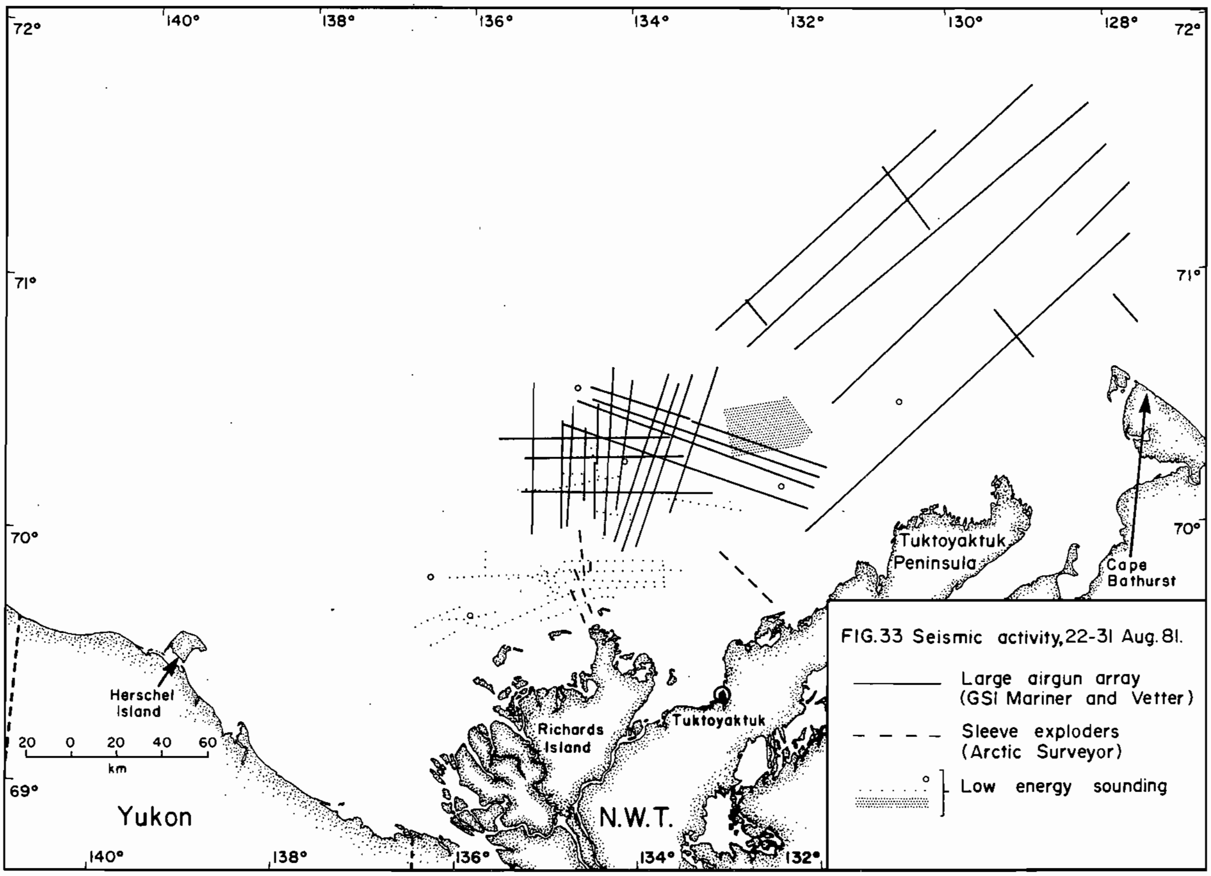


FIG.33 Seismic activity, 22-31 Aug. 81.

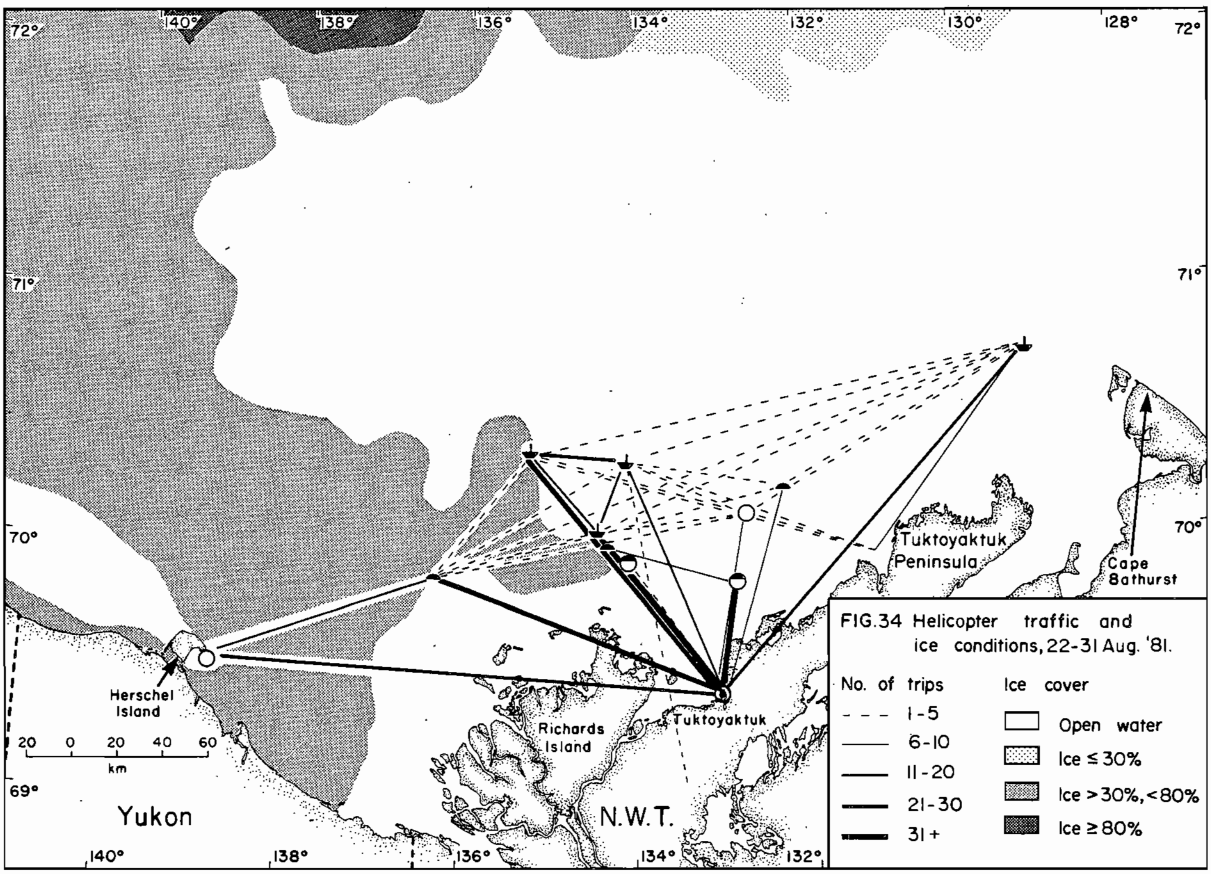


FIG.34 Helicopter traffic and ice conditions, 22-31 Aug. '81.

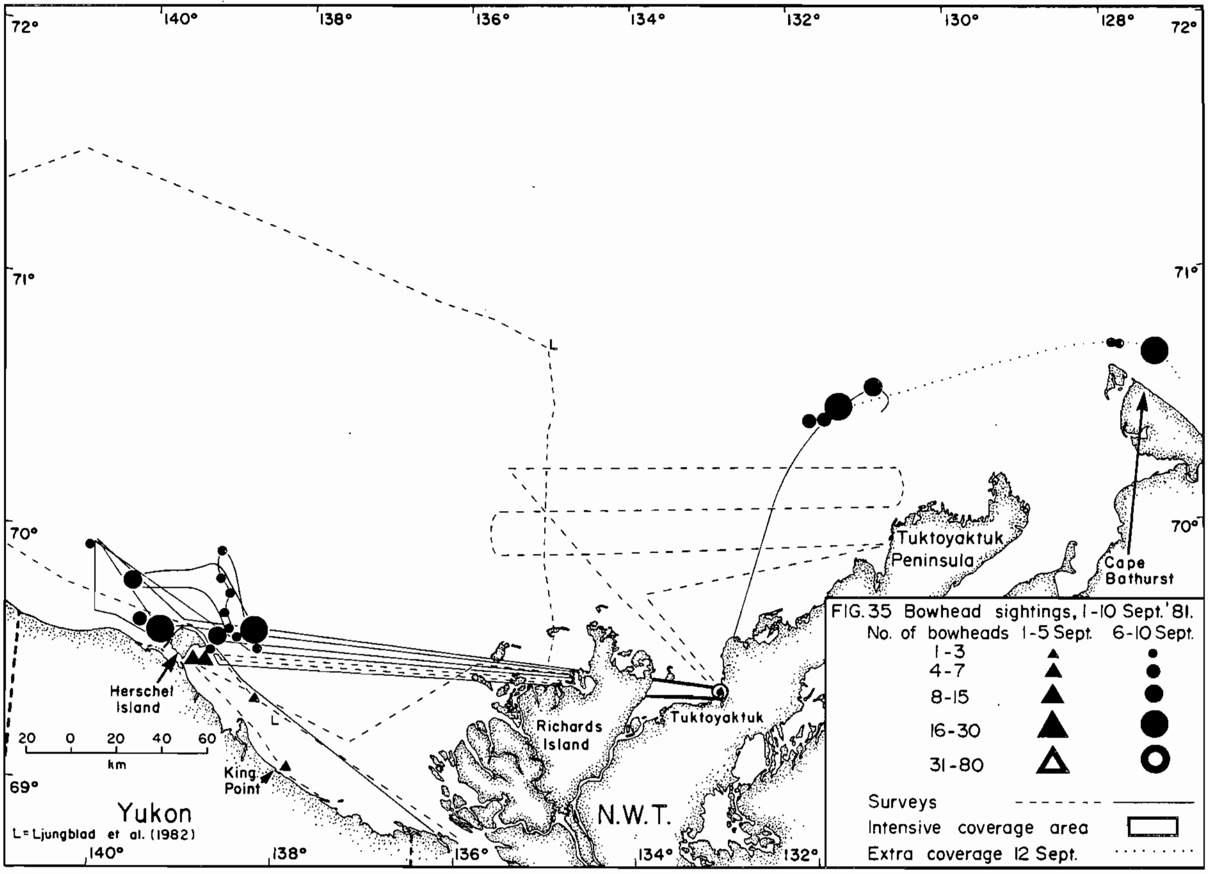


FIG. 35 Bowhead sightings, 1-10 Sept. '81.

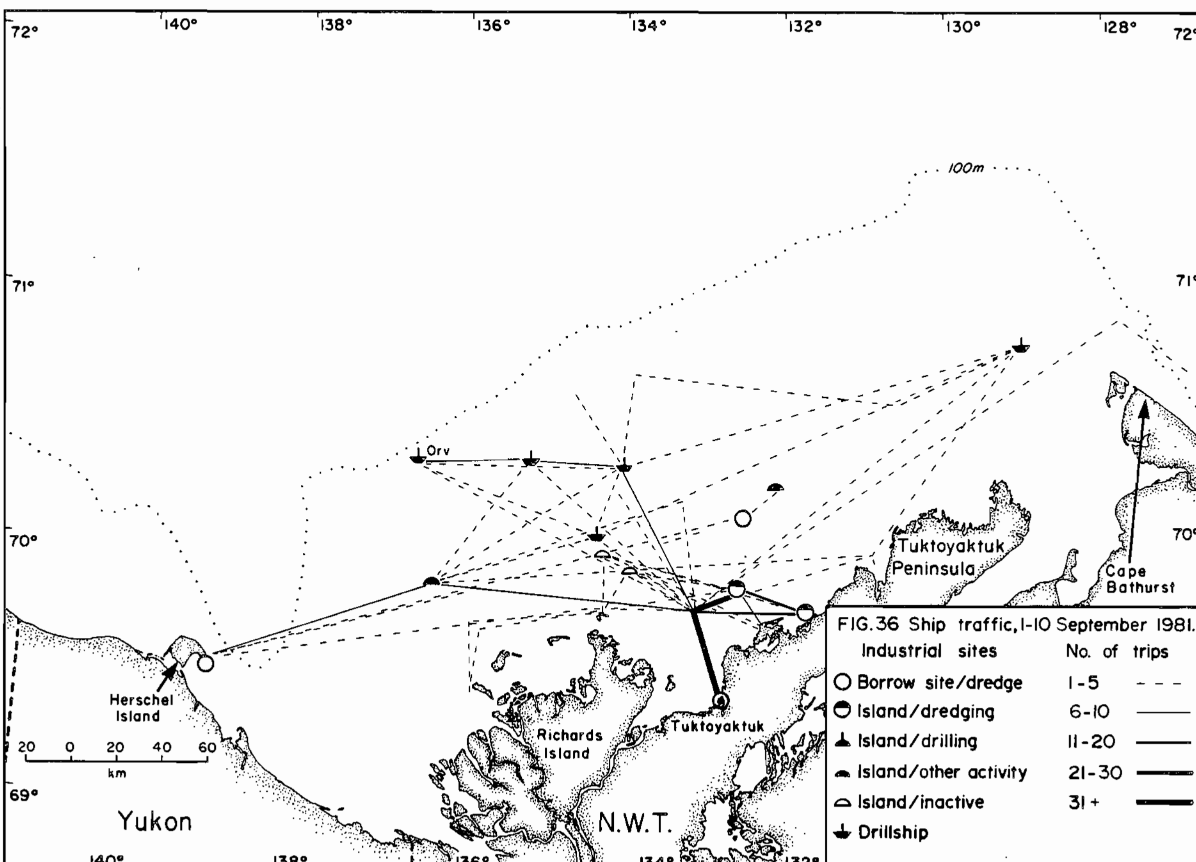


FIG. 36 Ship traffic, 1-10 September 1981.

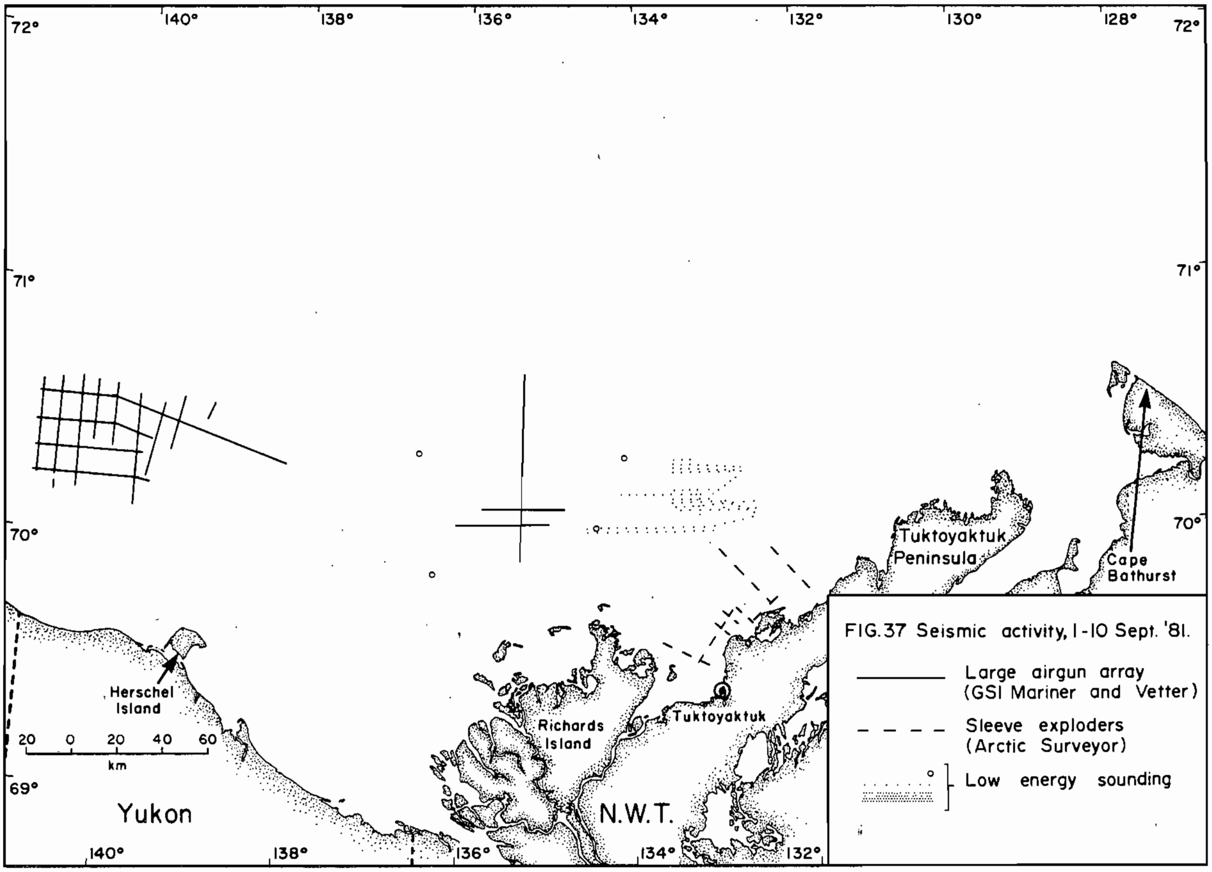


FIG. 37 Seismic activity, 1-10 Sept. '81.

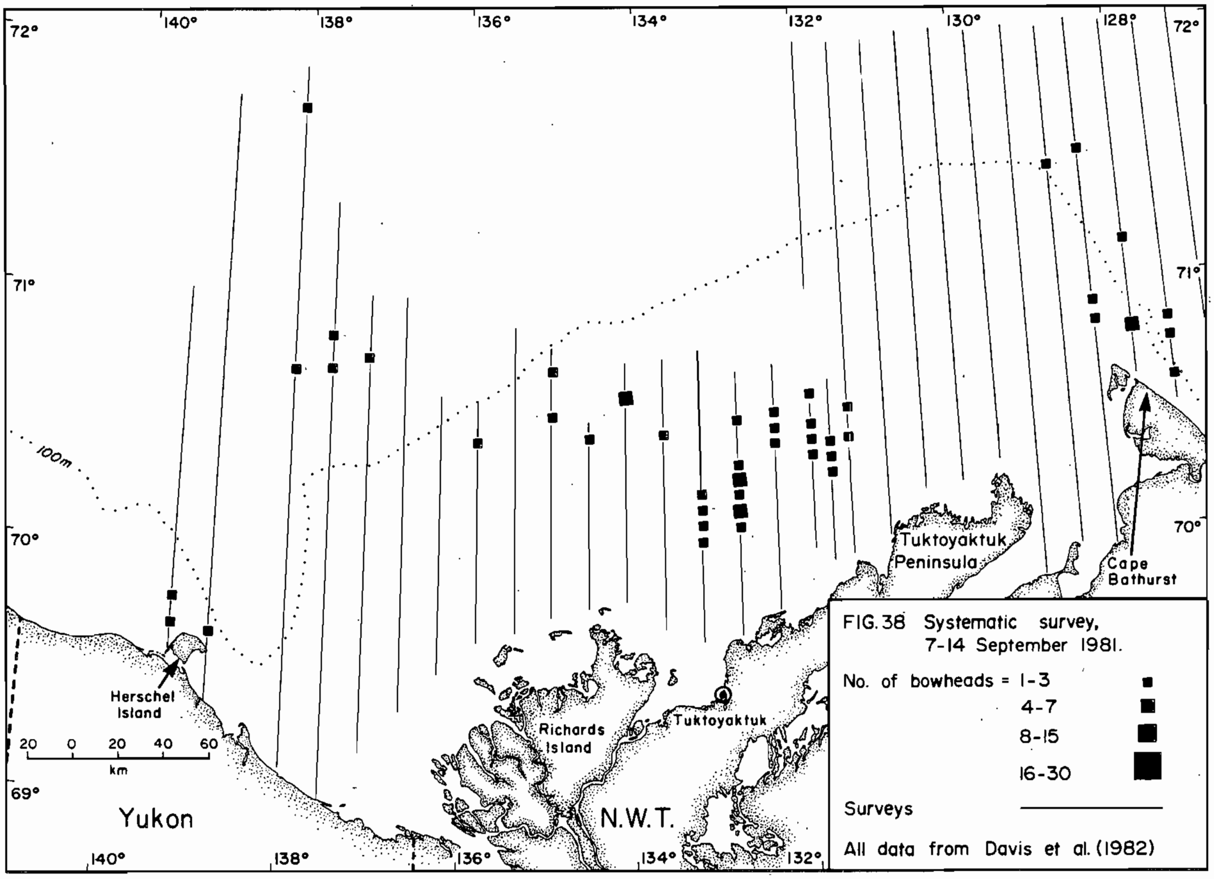


FIG. 38 Systematic survey, 7-14 September 1981.

At least six vessels performed low-energy sounding in 1981. The CSS 'Hudson' used small airguns in a broad swath off the Mackenzie Delta and Tuk Peninsula in late July and August (about 20 km wide; shaded areas in Figures 19, 23, 27, 33). The 'Arctic Sounder' shot lines north of the Mackenzie Delta and Tuktoyaktuk in August and early September. The other vessels generally operated at the specific sites shown as 'o' symbols on the seismic and sounding Figures.

Helicopters travelled from Tuktoyaktuk to most offshore industrial sites, and also between many of those sites (Figs. 24, 34). Because there was industrial activity farther west and east than in 1980, helicopters travelled over more of the eastern Beaufort Sea in 1981. Helicopters in use by the offshore operators in 1981 consisted of one Sikorsky 61, four Sikorsky 76, and about two Bell 212--an increase of two Sikorsky 76 machines from 1980 (Table 1).

Bowhead Distribution, 1981

Large scale features of bowhead distribution are better documented for 1981 than for 1980. There were clear differences in distribution between the two years, although some caution is necessary because of the differences in survey effort. Survey coverage in 1981 began earlier, and was much more extensive. Four systematic surveys of most of the southeastern Beaufort Sea were done between late July and early September (Davis et al. 1982). Many additional non-systematic flights were done during that project and during the behavior and disturbance study (Richardson 1982). Also, Ljungblad et al. (1982) flew into Canadian waters on several occasions. Relative to 1980, the 1981 coverage extended farther west and farther offshore, often beyond the edge of the continental shelf. In some periods, coverage also extended farther east.

Ice conditions were quite different than in 1980. There was extensive ice in the western parts of the Canadian Beaufort Sea in August 1981 but not in August 1980 (Figs. 24, 34; cf. Figs. 5, 13). Also, surveys extended farther offshore in 1981; surveyors often flew well into the pack ice in 1981 but rarely did so in 1980. Bowheads were often seen in this ice in 1981; whether they were present in corresponding areas in 1980 is unknown.

In **late July 1981,** few bowheads were present on the continental shelf within the eastern Beaufort Sea. During an intensive survey (19% coverage) of this entire area on 18-25 July, Davis et al. (1982) detected only six bowheads (Fig. 20). This corresponds to an uncorrected estimate of 45 whales (0.0006/km^2) in the surveyed area west of Cape Bathurst. Even after allowance for whales missed because they were below the surface when the survey aircraft passed over or for other reasons, only 255 whales were estimated to be in that area.

A larger number of whales was found east of Cape Bathurst, in Amundsen Gulf. The uncorrected and corrected estimates there were 178 and 994 whales (Davis et al. 1982). However, the total of 1248 whales estimated to be in Amundsen Gulf and the surveyed areas of the eastern Beaufort Sea is far less than the current 'best estimate' of the population size, which the International Whaling Commission now defines as 3857 (I.W.C. 1983). The majority of the population was presumably north or west of the area surveyed systematically by Davis et al. Limited coverage of pack ice north of the 100 m contour and beyond the area of systematic coverage confirmed that more bowheads were present far offshore (e.g., Fig. 17).

Only a small proportion of the bowhead population was in areas near industrial activities in late July 1981. Some of the whales off the Yukon coast were not far from seismic vessels (Fig. 20 vs. 19). We know from measurements in 1982 that noise from seismic ships can be detected up to 70 km away in that area (Richardson et al. 1983b).

During **early August 1981,** bowheads were apparently moving into the southeastern Beaufort Sea from the north. Extensive non-systematic surveys showed a concentration of whales near and just south of the southern edge of the pack ice, which was also near the edge of the continental shelf (Fig. 21). Smaller groups were present in open water on the shelf. Numbers in these areas were clearly higher than in late July.

In early August, few whales were in the area of offshore drilling and island construction--in marked contrast to the situation in early August 1980 (cf. Fig. 2). However, some whales were not far north of industrial operations. About 30 whales were seen only 21 km north of Tarsiut on 13 August (Fig. 21). Some of the whales near the edge of the continental shelf north of the Mackenzie Delta could probably hear noise from seismic exploration (Fig. 23 vs. 21). Greene (1983) describes seismic noise recorded near whales in this area on 5 August 1981. There was no evidence that this particular group of whales was reacting to the seismic ship, which was about 50 km away (Richardson et al. 1983b).

From 5 to 17 August 1981, a second systematic survey was done (Fig. 29; Davis et al. 1982). Coverage was good from the Tuk Peninsula east through Amundsen Gulf, but limited off the Mackenzie Delta and minimal off the Yukon. However, the results confirm that large numbers of whales were moving into the southeastern Beaufort Sea. Some may have come from Amundsen Gulf, where numbers were reduced from an estimated 994 to 228. However, most must have come from the north. An estimated 2860 whales (with broad confidence limits) were present off the Mackenzie Delta, with 404 more off the Tuk Peninsula.

Very limited coverage off the eastern Yukon showed that many more bowheads were present there, but there was no systematic coverage farther west. Ljungblad et al. (1982) saw no whales near Herschel Island on 15 August, but their route was closer to shore than the locations where bowheads were seen in more easterly areas. Thus, there is no information about the western limit of distribution at this time, except that it was west of 137°34'.

In **mid August 1981**, the area of greatest whale abundance was off the Mackenzie Delta and at least the eastern part of the Yukon. Most of our non-systematic coverage was in waters <50 m deep off the Mackenzie Delta, but we and Ljungblad et al. (1982) obtained some coverage off the Yukon (Fig. 25). Many whales were found between the 20 and 50 m depth contours off the Delta, and a few were in shallower water. Most of the whales were just west or north of the area of most intense industrial activity. The aforementioned systematic survey on 5-17 August showed that large numbers of bowheads were in deeper waters farther to the west and north (Fig. 29).

In mid August 1980, many whales were well within the area of most intense industrial activity, whereas in 1981 most remained at least a few kilometres farther west or north. Many fewer whales were present off the Tuktoyaktuk Peninsula and in water <20 m deep in mid August 1981 than in 1980 (Figs. 25 and 29 vs. Fig. 6). Industrial activity was more extensive off the Tuk Peninsula in mid August of 1981 than of 1980. It is not known whether the increased industrial activity had any connection with the reduced utilization of this area in 1981.

In **late August 1981**, some bowheads were still in shallow water off the Mackenzie Delta (Fig. 31). However, the available data, particularly the third systematic survey on 19-29 August, showed that most were widely distributed in deeper water NW, N and NE of the Delta (Fig. 30). The only concentration seen in shallow water during the third systematic survey was off the Delta on 24 August. Davis et al. (1982) estimated that 583, 1496 and 839 bowheads were in the sampled parts of the Yukon, Delta and Tuk Peninsula zones, respectively (total 2918 ± s.e. 1015). There were apparently somewhat fewer whales off the Delta and more off the Tuk Peninsula than during the 5-17 August period, although the broad confidence limits on all the estimates make comparisons questionable.

Many fewer whales were off the Tuk Peninsula in late August 1981 than at the corresponding time in 1980 (Figs. 30, 31 vs. 10). The 839 estimate for this area in 1981 includes a correction for whales below the surface; the uncorrected estimate was 150. In contrast, the uncorrected estimate for the part of this area surveyed on 21-24 August 1980 was 755 (Renaud and Davis 1981). Furthermore, the distribution of whales within the Tuk Peninsula zone was very different in the two years. In 1980, they were concentrated in the western half, including very close to shore; in 1981, they were concentrated far offshore.

In late August, whales were numerous in waters deeper than 50 m as far west as Herschel Island, but infrequent from there to the Alaskan border (Fig. 30). Observers were at King Point, along the Yukon coast, from 19 August to 3 September. They detected bowheads on 18 and 19 August, and on 3 September. Observers were at the east end of Herschel Island from 23 August to 13 September; whales were first sighted there on 29 August (Würsig et al. 1982).

In late August, most whales were on or beyond the outer part of the continental shelf and were beyond the area of most industrial operations. However, some whales far off the Tuk Peninsula were close to seismic lines (Fig. 30 vs. 33). On 24-26 August, the captain of the 'GSI Mariner' saw groups of 2-4 bowheads an estimated 2-5 km from the ship while it was shooting in this area (Richardson et al. 1983b). The few whales in shallow water off the Mackenzie Delta were near various industrial operations. One group seen there on 25 August was only 6-8 km from a seismic ship; behavior was not noticeably unusual (Fraker et al. 1982; Richardson et al. 1983b).

In **early September 1981,** the majority of the Western Arctic bowheads were apparently still in Canadian waters. Based on their fourth systematic survey, Davis et al. (1982) estimated that over 2539 bowheads were still present on 7-14 September, and their surveys and estimates did not include all of the eastern Beaufort Sea (Fig. 38). The whales were widely distributed from east of Cape Bathurst to west of Herschel Island. At least off the Tuk Peninsula, many whales were closer to shore than they had been in late August (Fig. 38; cf. Fig. 30). This shift was contrary to what was seen at this time in 1980, when whales off Tuk Peninsula tended to be farther offshore than in late August.

Bowheads were apparently more numerous around Herschel Island in early September 1981 than at the corresponding time in 1980 (Fig. 35 vs. 14). Observers on the island saw whales within a few kilometres from shore until 10 September. There were no systematic surveys between Herschel Island and the Alaska border (141°W), but other surveys showed that whales were present there in early September (Fig. 35). Ljungblad et al. (1982) found a concentration of up to 15 or more whales just east of 141°W on 12-17 September.

The concentrations of whales off the Tuk Peninsula and Mackenzie Delta in early September were not far from seismic exploration, and some of those off the Delta were in the general area with three drillships and supporting activities. There was also seismic exploration northwest of Herschel Island in early and mid September, and some of the whales seen just east of 141°W were close to active seismic boats (Ljungblad et al. 1982).

In the Alaskan Beaufort Sea, the first autumn sighting was on 7 September just west of the Alaska-Yukon border. Single whales were taken by Eskimos off Barter Island on 8, 11 and 22 September, but survey results suggested that few whales moved west of Barter Island until about 28 September (Ljungblad et al. 1982). Bowheads were present at least as far east as Barter Island as late as 9 October, and were still present in the central Alaskan Beaufort on 15 October when surveys ended.

Bowhead Distribution and Industrial Activities in 1982

The information for 1982 appears in Figures 39 to 55. The period 1 August to 10 September is considered.

Industrial Activities, 1982

The level of industrial activities increased again in 1982. Esso and Dome continued their operations with greater intensity, and Gulf expanded its independent operations. Four hopper dredges were operating in 1982 -- two more than during the summer of 1981. Construction of a subsea berm began at Nerlerk, where water is deeper than at any previous island or caisson site in the Canadian Beaufort Sea.

Drilling at the Tarsiut caisson-retained island began in winter and continued until the first week of August. From then until September well testing and other operations continued; several support vessels were usually present around Tarsiut in August. Three drillships were at specific wellsites throughout our study period (Fig. 40); the fourth was at Nerlerk until 28 August and then moved to Orvilruk (Fig. 48).

Two suction and four hopper dredges were active in 1982. Of the former, the 'Beaver Mackenzie' worked at Itiyok throughout the study period, and the 'Aquarius' alternated between Uviluk and McKinley Bay. The hopper dredges

'W.D. Gateway' and 'Geopotes IX' worked on the construction of four islands or subsea berms for caissons: Kadluk and Itiyok in shallow water and Kogyuk and East Amauligak in deeper water. The 'Hendrik Zanen' and 'Geopotes X' brought material mainly to Uviluk and Nerlerk, where berms for Dome's semi-submersible drilling caisson were under construction. Numerous borrow sites were used (Fig. 40), but Ukalerk was used most heavily. On some days all four hopper dredges loaded at Ukalerk; after 26 August, 'Geopotes IX' alone made about five trips per day carrying fill from Ukalerk to Kogyuk.

The area of frequent vessel movements extended less far to the east and west but somewhat farther to the north in 1982 than in 1981. There was no industrial activity off the eastern Tuktoyaktuk Peninsula in 1982, where a drillship worked in 1981. There were again a few trips west to Herschel Island, but industrial activity there was reduced from 1981. Vessels went farther north in 1982 because a drillship operated at Kenalooak, the northernmost site yet drilled in the eastern Beaufort. Kenalooak was also drilled in 1980. NTCL vessels made one round trip to Prudhoe Bay and several trips far to the east; dredges occasionally travelled to Banks Island. Island clean-up occurred at Alerk from mid July to early August.

Seismic exploration by two high-energy vessels, the 'GSI Mariner' and 'Arctic Surveyor', was primarily off the Mackenzie Delta and Yukon coast. The 'Canmar Teal', using a small (300 cu in) array of airguns, worked mainly in 14 small areas, primarily off the Delta and north of Tuktoyaktuk (Figs. 41, 45, 49, 55). Relative to 1981, seismic exploration was more extensive off the Yukon coast and less so off the Tuk Peninsula. It was extensive off the Delta in both years.

Low-energy sounding was done from seven vessels operating at about 26 locations, most <1 km^2 in size. Sounding sites were 15-85 km from shore off the Delta and western Tuk Peninsula.

Helicopters travelled frequently from Tuktoyaktuk and occasionally McKinley Bay to the various offshore sites. Helicopter traffic, like vessel traffic, extended less far to the west and east but farther to the north in 1982 than in 1981 (Figs. 42, 50). More helicopters were in use in 1982 than in earlier years (Table 1).

Bowhead Distribution, 1982

Bowhead distribution in the eastern Beaufort Sea from early August to early September 1982 is reasonably well documented, but there were fewer systematic surveys than in 1981, and no coverage of Amundsen Gulf. Distribution and movement patterns differed from both 1980 and 1981. Surveys were conducted in the Alaskan Beaufort Sea in August-October 1982 (Ljungblad 1983; Ljungblad et al. in prep.), and some of these surveys extended into the western part of the Canadian Beaufort.

There was considerable ice off the Yukon coast in 1982, especially after 16 August (Figs. 42, 50). However, to the north of the Delta and Tuk Peninsula, the southern limit of ice was well north of the shelf break--much farther offshore than in 1980 or 1981.

In **early August 1982,** we found bowheads in open water northwest of the Mackenzie Delta and in pan ice north of Herschel Island (Fig. 39). Ljungblad et al. (in prep.) found bowheads northwest of Herschel Island, just east of the Alaskan border (Fig. 39). Intensive coverage within the main industrial area and limited coverage farther north and east found no bowheads (Fig. 39). Many of the whales off the Delta were travelling west. They were somewhat beyond the main area of industrial activity; the sighting closest to any active offshore site was 21 km north of Tarsiut. However, there was seismic exploration in this area, and on one day seismic noise was measured near whales (Richardson et al. 1983b). Almost all whales seen in early August were on the outer part of the continental shelf or the shelf break (depths about 40-600 m).

Distribution in early August was very different in 1982 than in 1980, when there were many whales in the shallow waters of the industrial area just off the Mackenzie Delta. Distributions in 1981 and 1982 were more similar, but in 1981 the whales were more widespread on the outer shelf and shelf break, and they seemed to be travelling south rather than west.

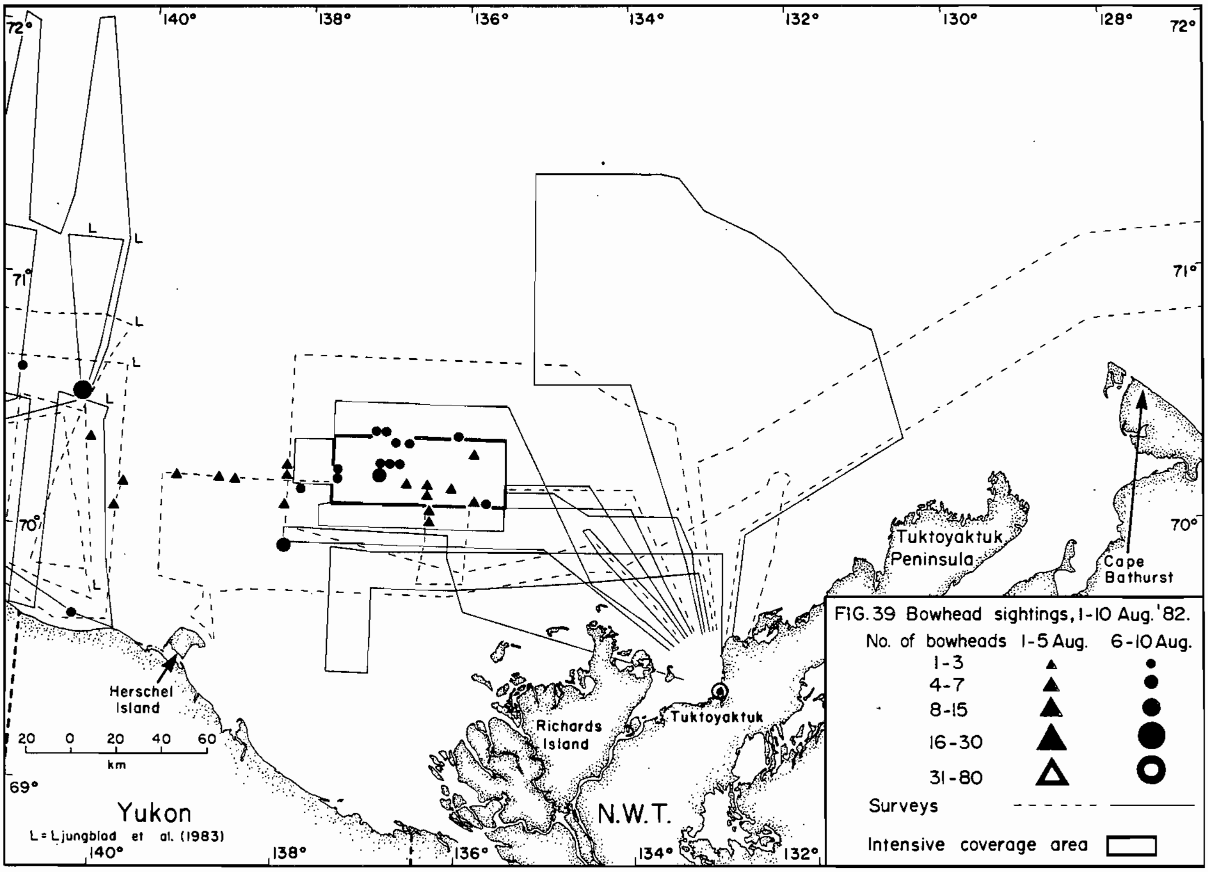


FIG. 39 Bowhead sightings, 1-10 Aug. '82.

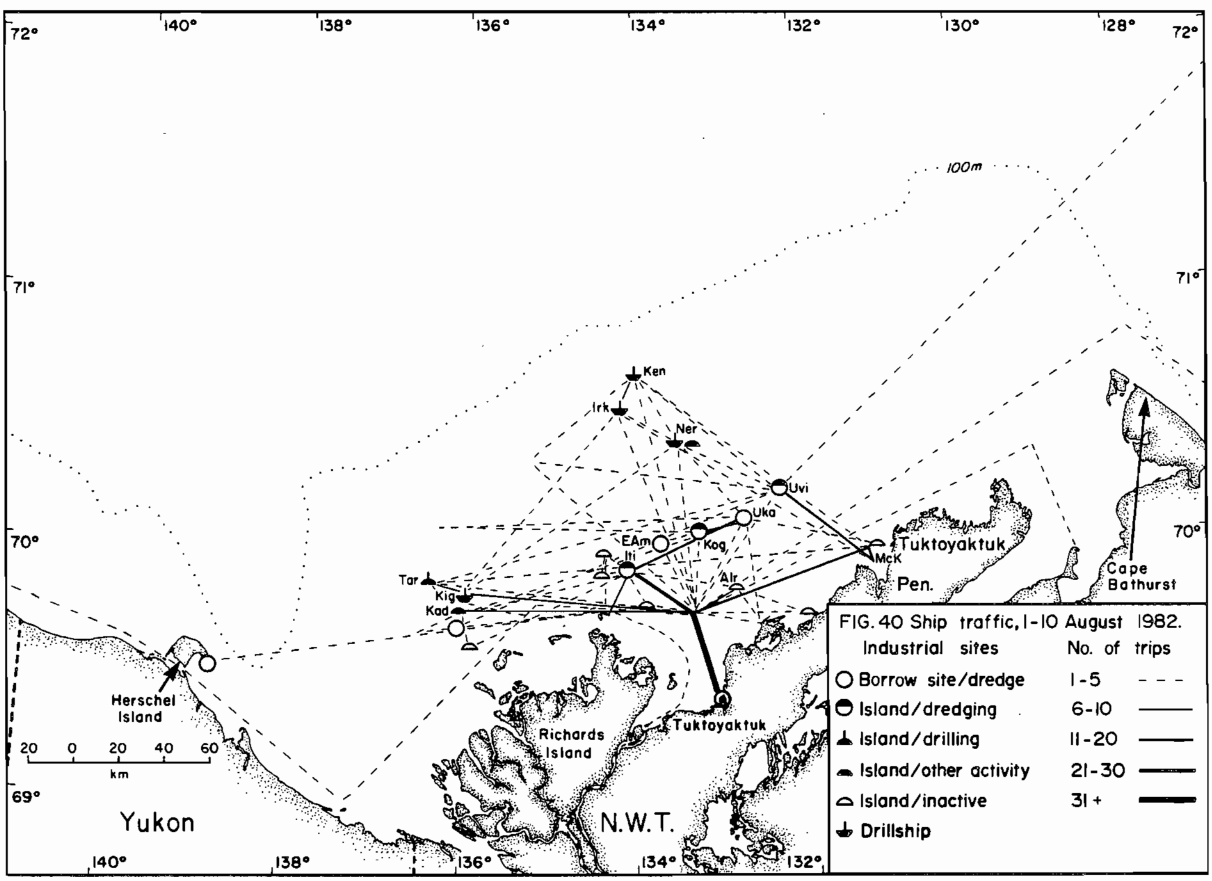


FIG. 40 Ship traffic, 1-10 August 1982.

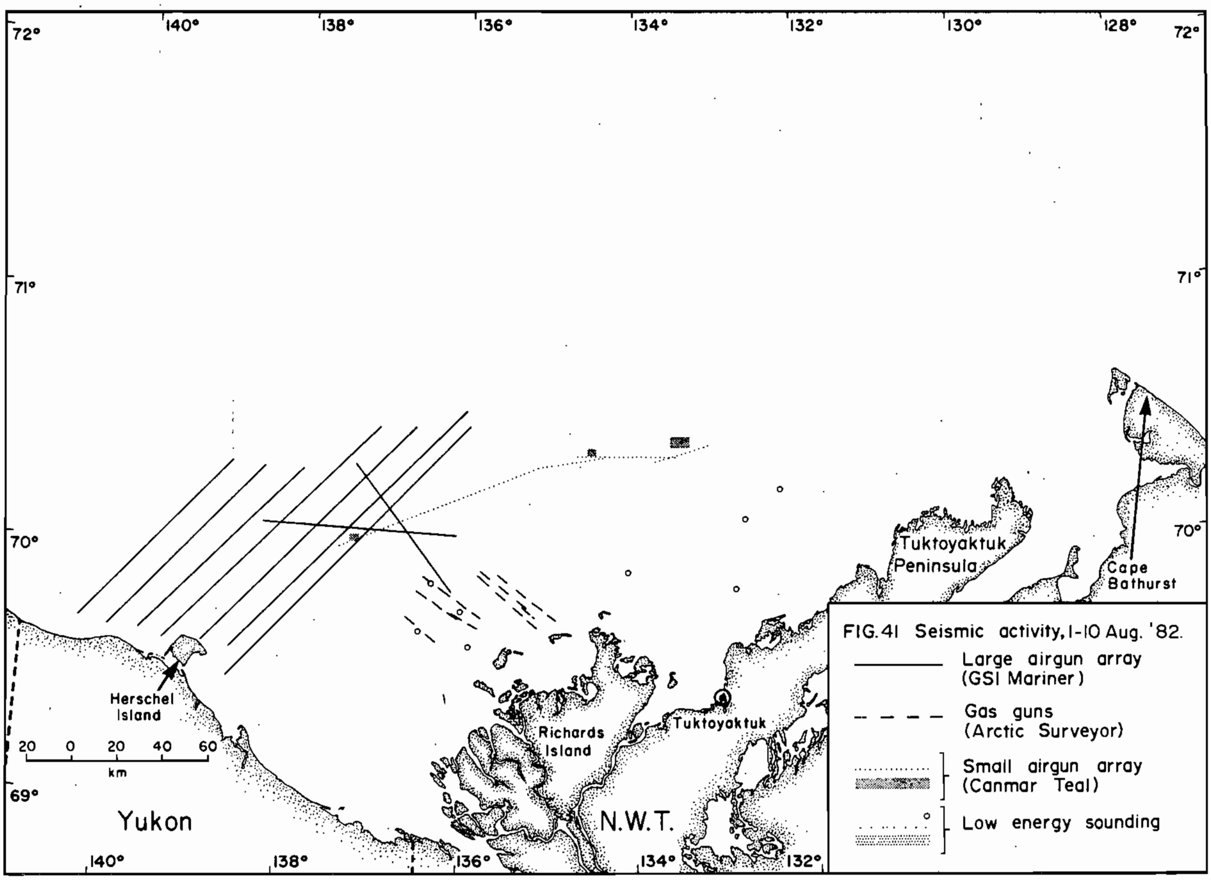


FIG.41 Seismic activity, 1-10 Aug. '82.

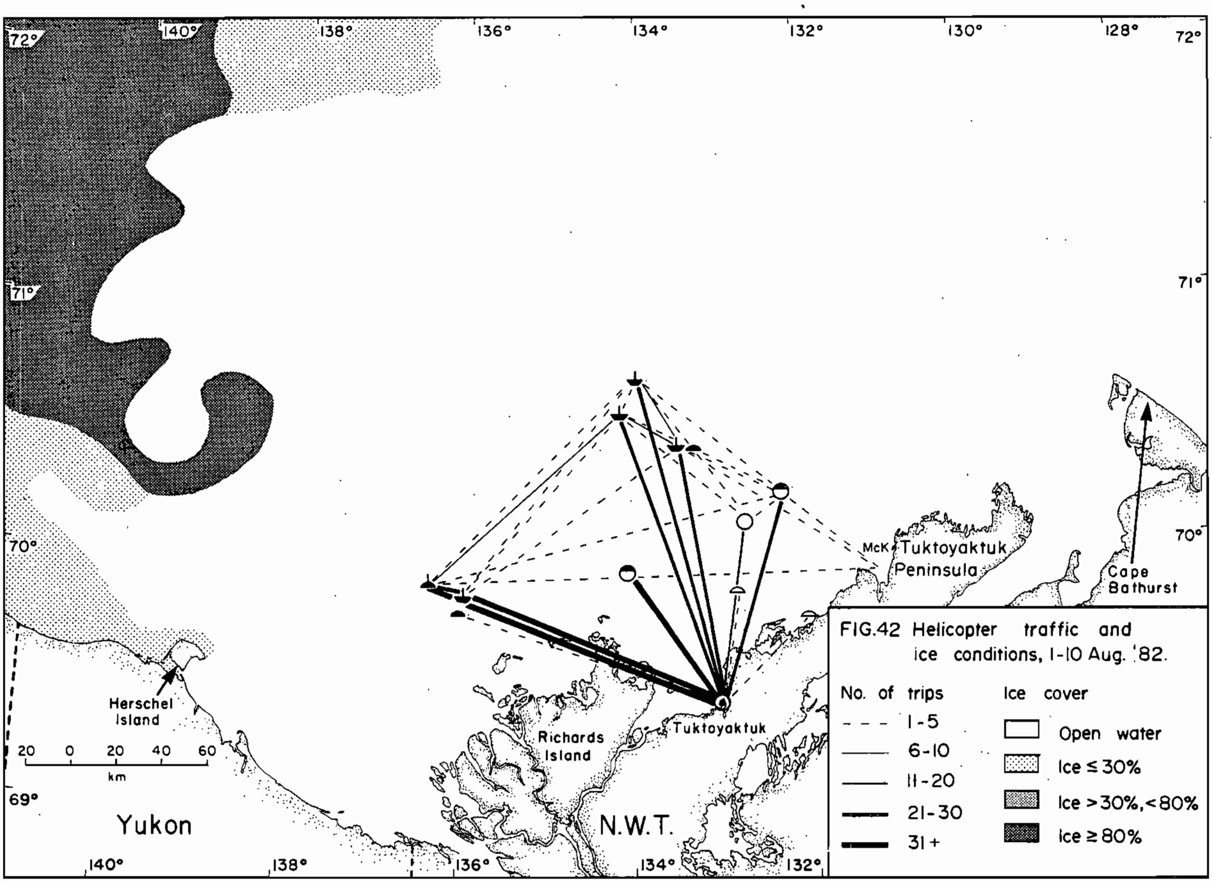


FIG.42 Helicopter traffic and ice conditions, 1-10 Aug. '82.

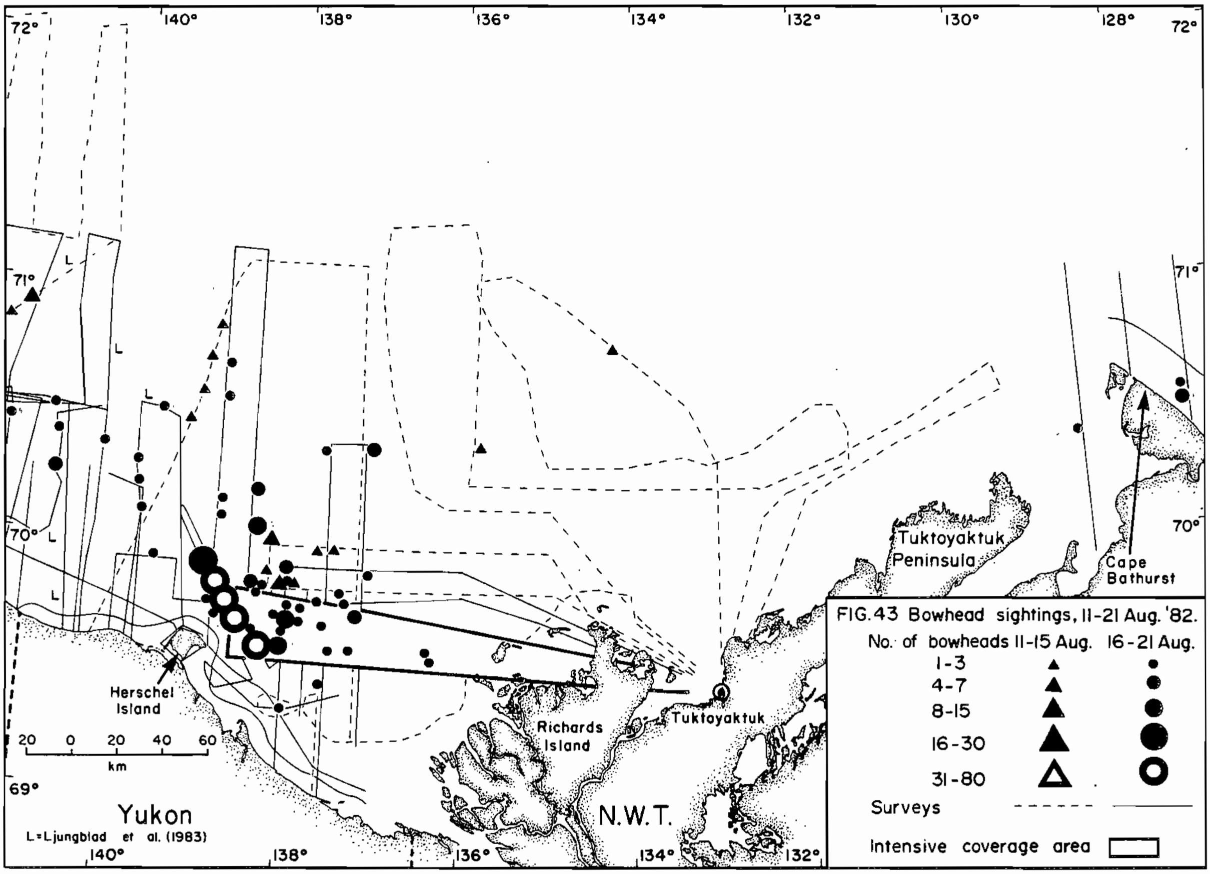


FIG.43 Bowhead sightings, 11-21 Aug. '82.

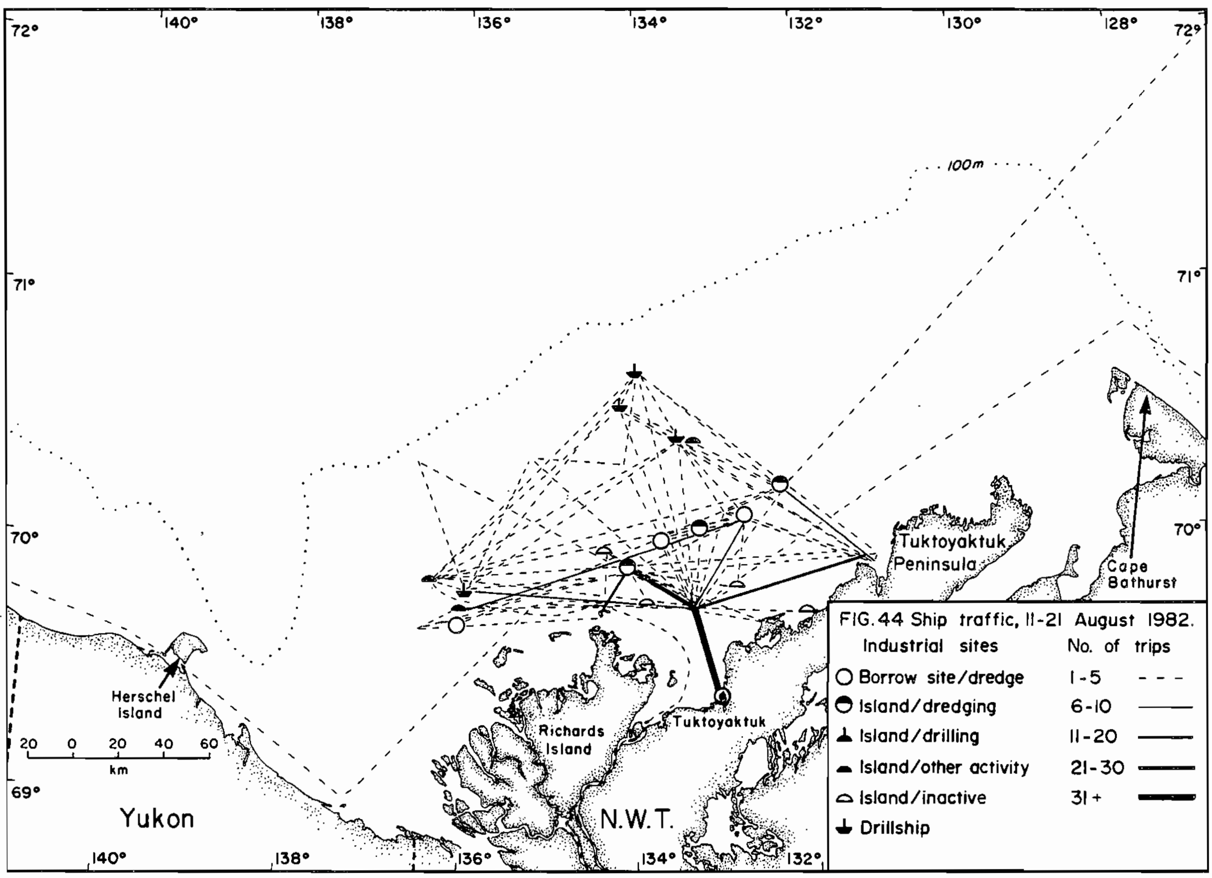


FIG.44 Ship traffic, 11-21 August 1982.

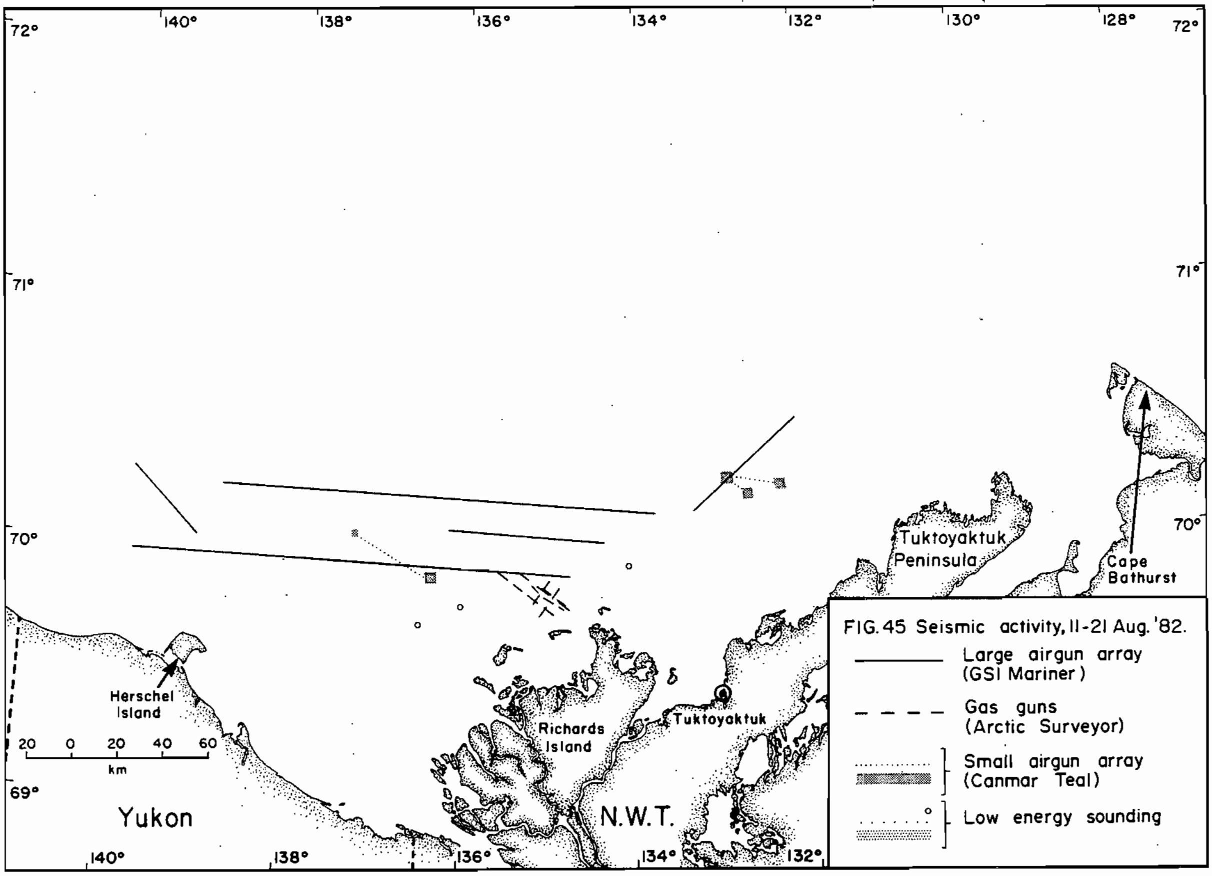


FIG. 45 Seismic activity, 11-21 Aug. '82.

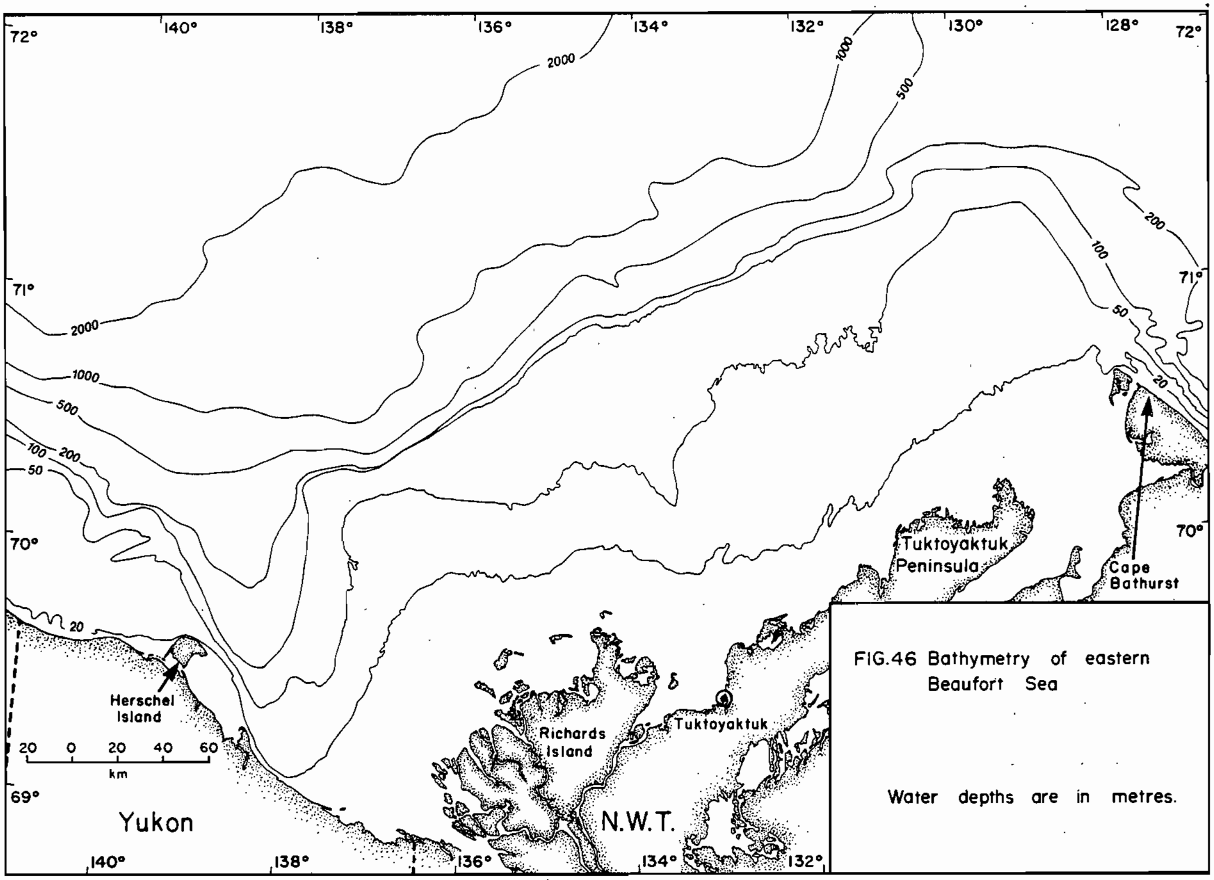


FIG. 46 Bathymetry of eastern Beaufort Sea

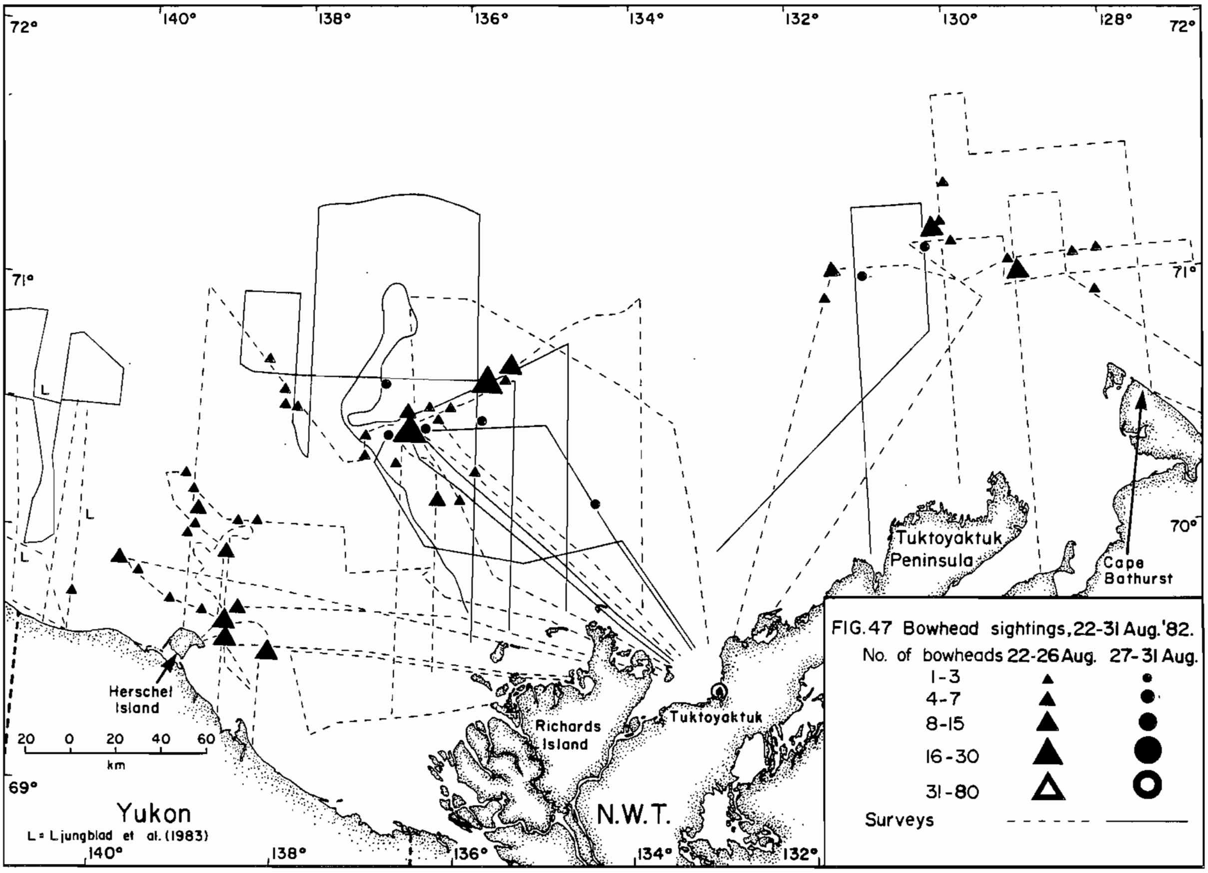


FIG. 47 Bowhead sightings, 22-31 Aug. '82.

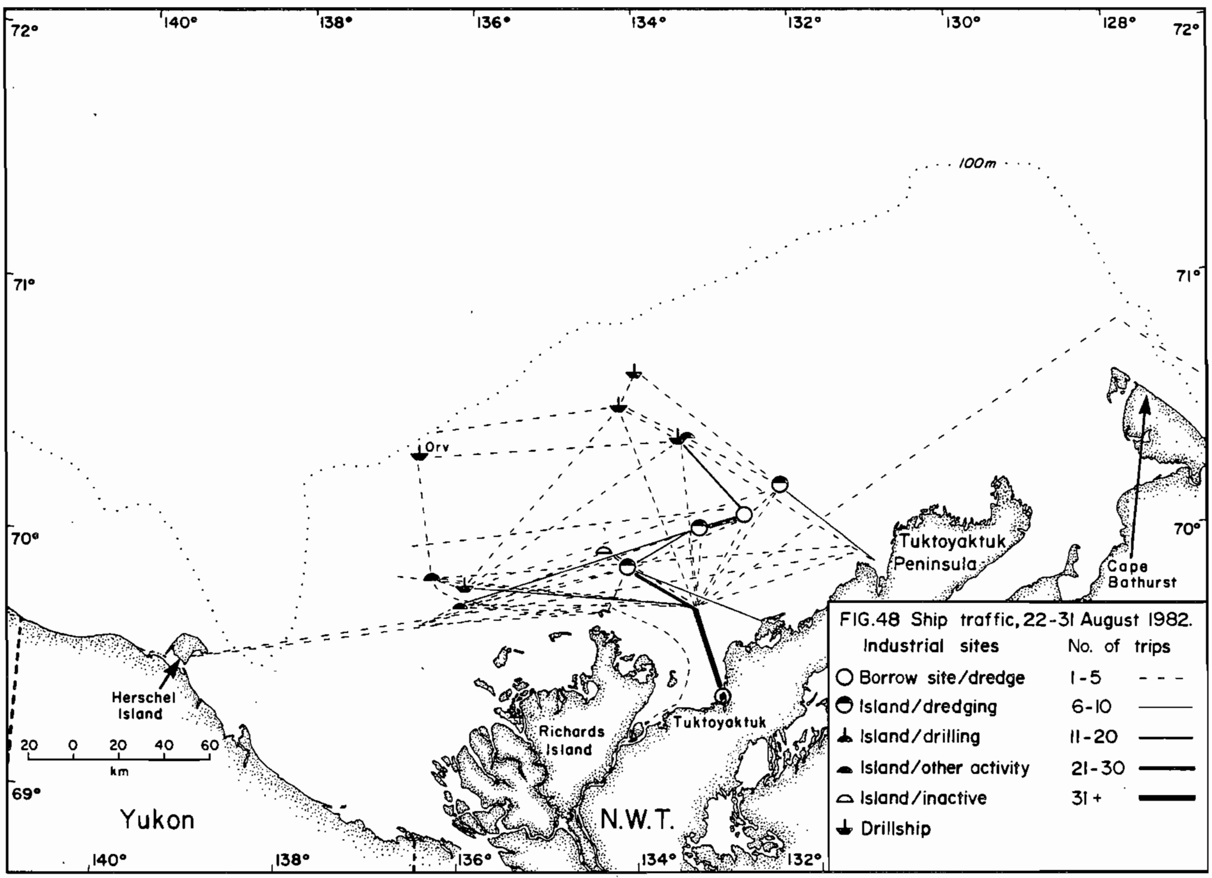


FIG. 48 Ship traffic, 22-31 August 1982.

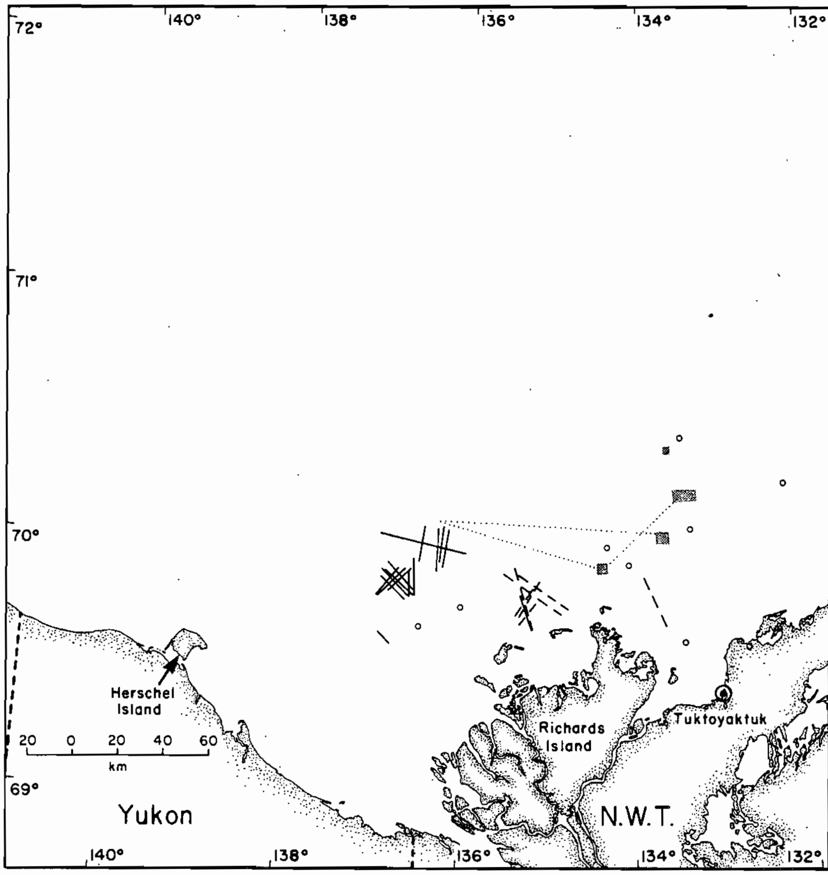


FIG. 49 Seismic activity, 22-31 Aug. '82.

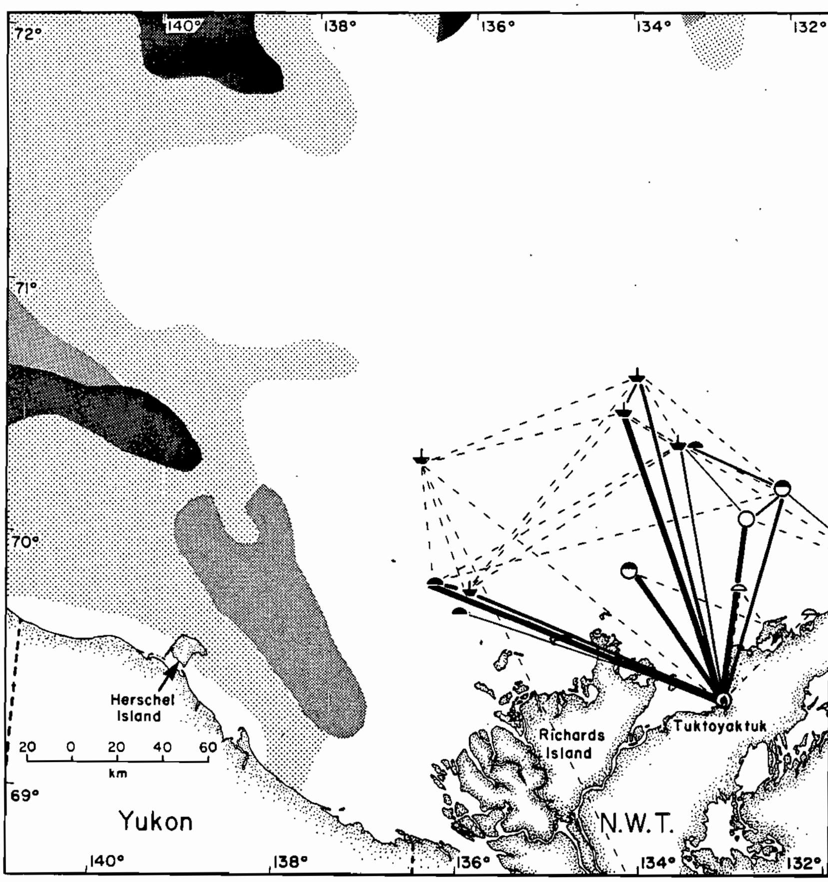


FIG. 50 Helicopter traffic and ice conditions, 22-31 Aug. '82.

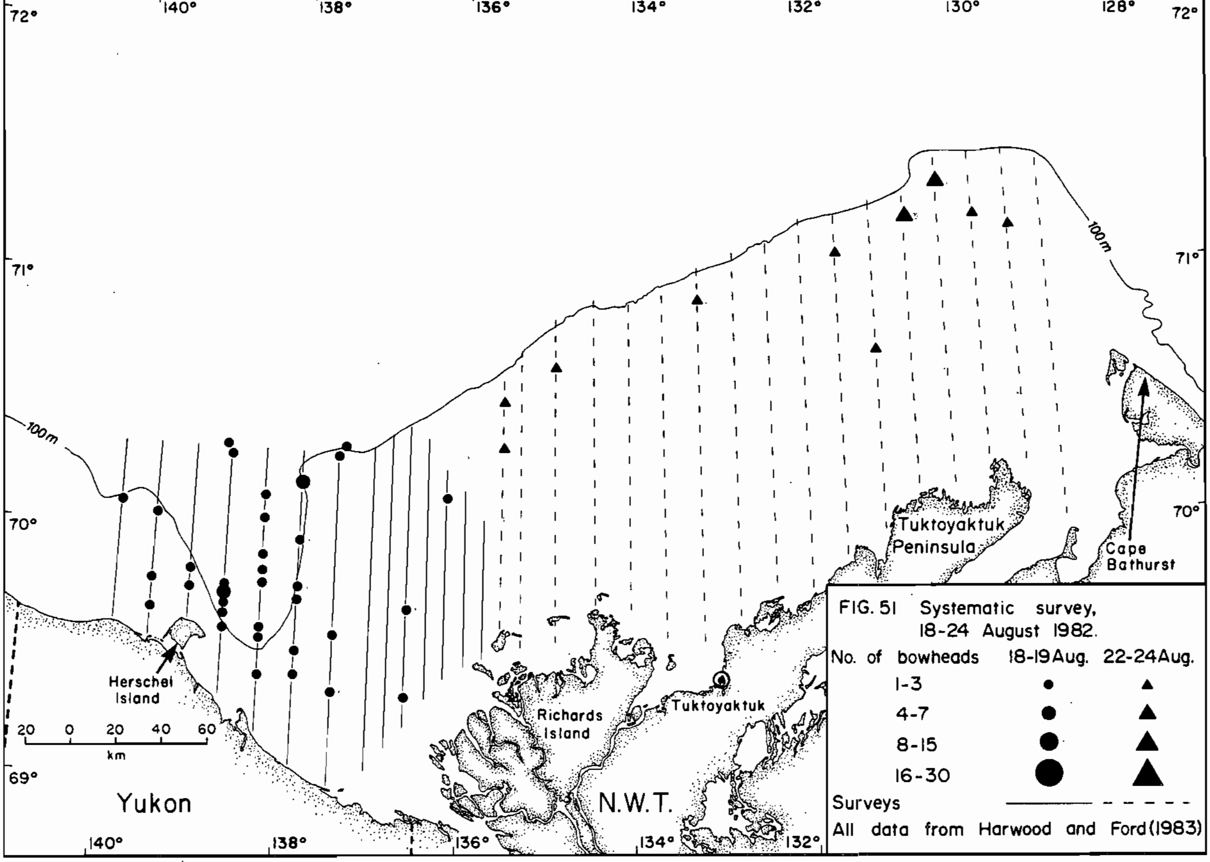


FIG. 51 Systematic survey, 18-24 August 1982.

No. of bowheads	18-19 Aug.	22-24 Aug.
1-3	●	▲
4-7	●	▲
8-15	●	▲
16-30	●	▲
Surveys	———	- - - -

All data from Harwood and Ford (1983)

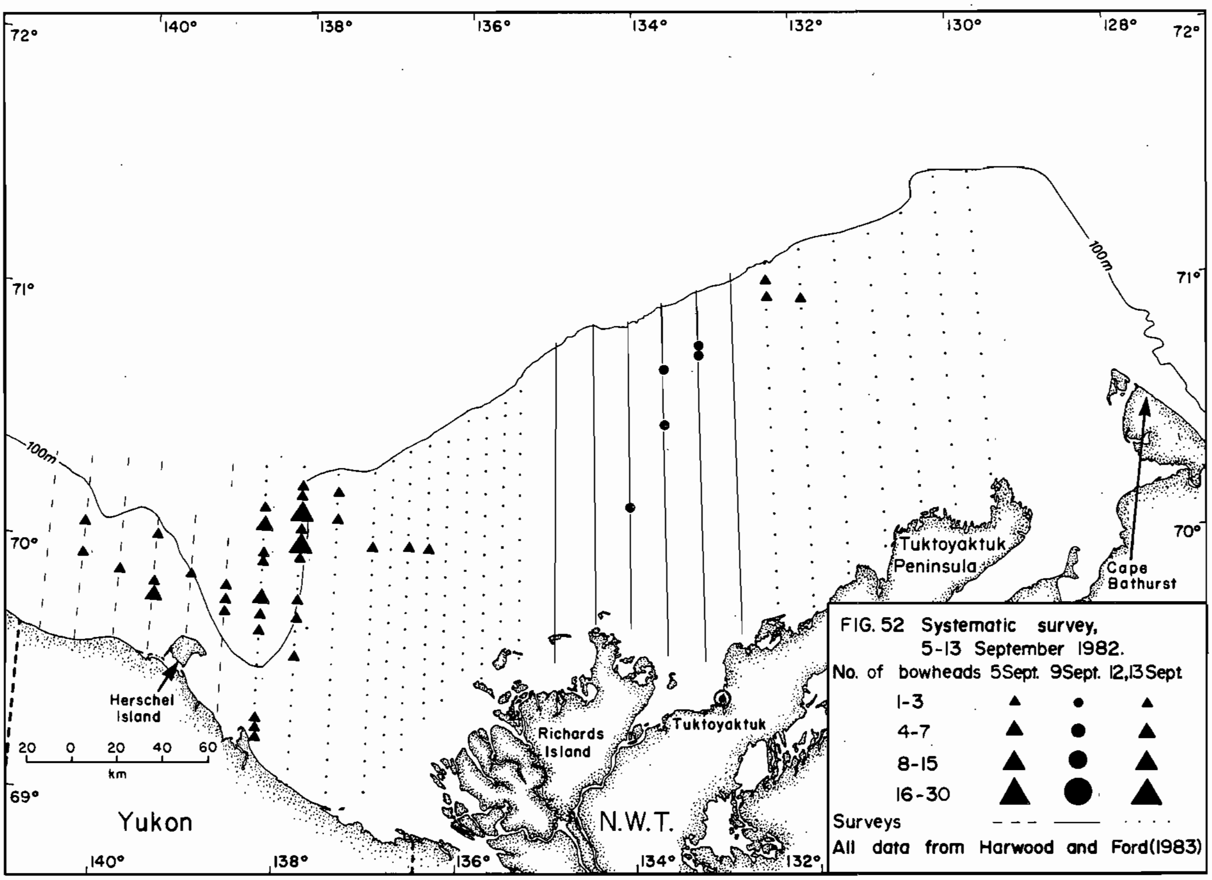


FIG. 52 Systematic survey, 5-13 September 1982.

No. of bowheads	5 Sept.	9 Sept.	12,13 Sept
1-3	▲	●	▲
4-7	▲	●	▲
8-15	▲	●	▲
16-30	▲	●	▲
Surveys	- - -	———	· · · ·

All data from Harwood and Ford (1983)

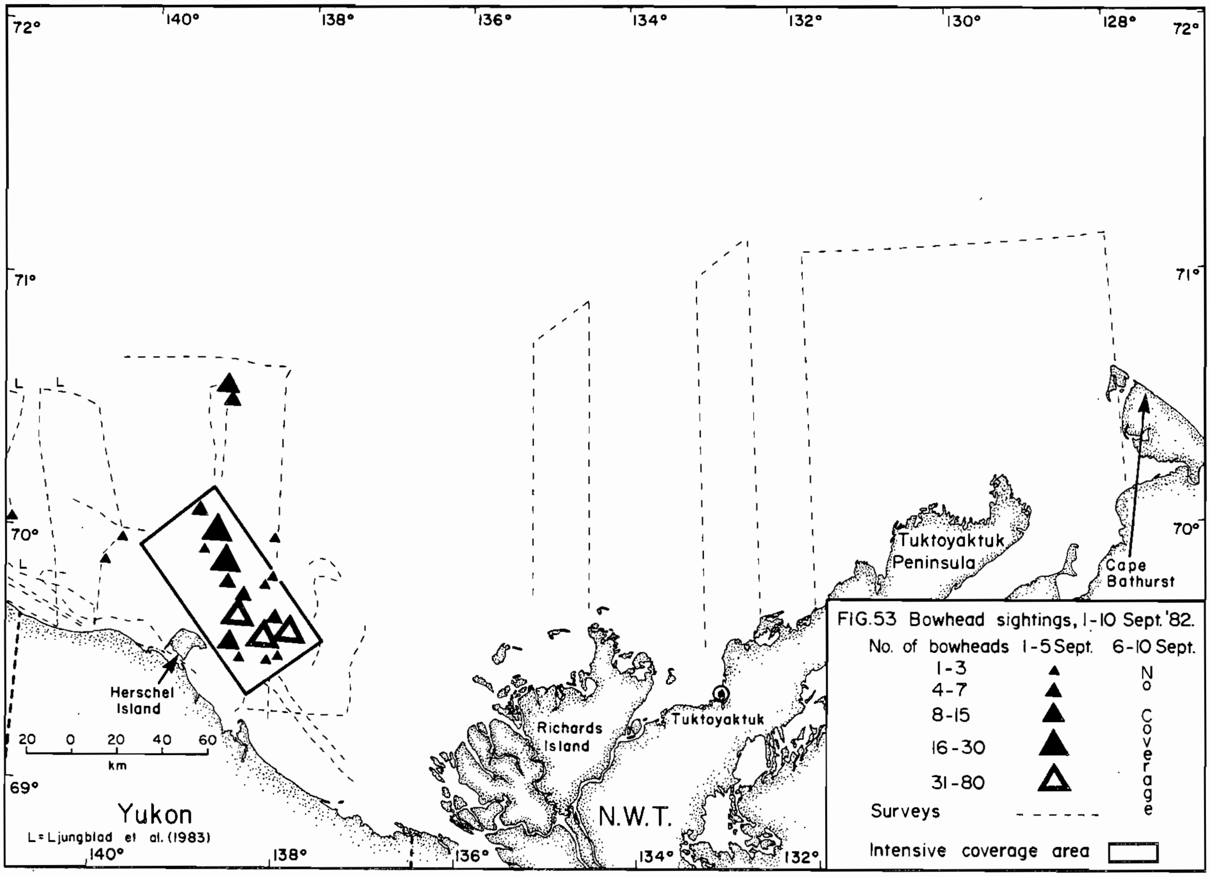


FIG.53 Bowhead sightings, 1-10 Sept.'82.
No. of bowheads 1-5 Sept. 6-10 Sept.
1-3
4-7
8-15
16-30
31-80
No Coverage
Surveys
Intensive coverage area
Tuktoyaktuk Peninsula
Cape Bathurst
Herschel Island
Richards Island
Tuktoyaktuk
Yukon
N.W.T.
L = Ljungblad et al. (1983)
km
20 0 20 40 60
72° 71° 70° 69°
140° 138° 136° 134° 132° 130° 128°

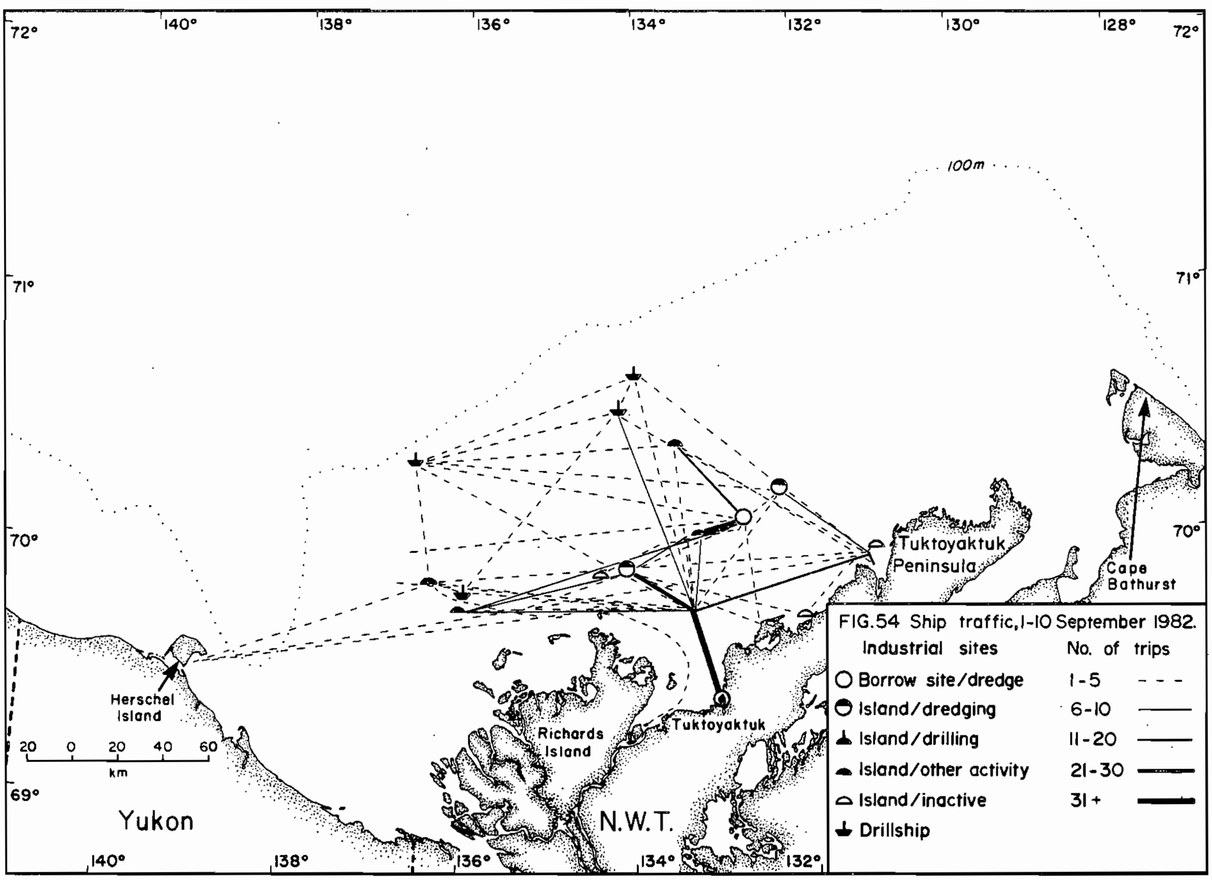


FIG.54 Ship traffic, 1-10 September 1982.
Industrial sites
No. of trips
Borrow site/dredge 1-5
Island/dredging 6-10
Island/drilling 11-20
Island/other activity 21-30
Island/inactive 31+
Drillship
100m
Tuktoyaktuk Peninsula
Cape Bathurst
Herschel Island
Richards Island
Tuktoyaktuk
Yukon
N.W.T.
km
20 0 20 40 60
72° 71° 70° 69°
140° 138° 136° 134° 132° 130° 128°

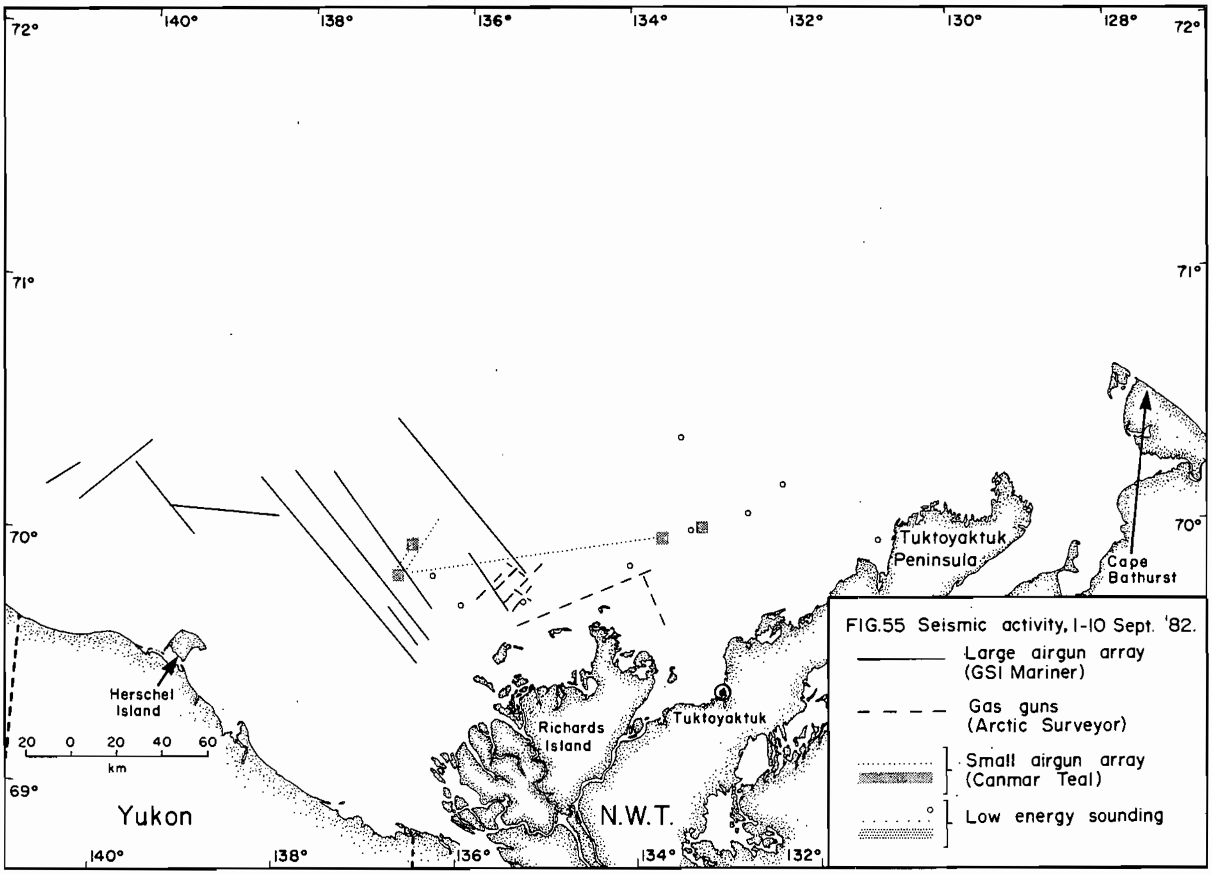


FIG.55 Seismic activity, 1-10 Sept. '82.

Bowheads were also present well offshore from the Barter Island, AK, area in early August 1982 (D.K. Ljungblad, pers. comm.). Bowheads were not found in the Alaskan Beaufort in August of 1980-81, but in those years the August survey coverage rarely extended far offshore (Ljungblad et al. 1982).

In **mid August 1982**, many bowheads were near Herschel Island, and there were apparently considerable numbers well to the north and northwest of Herschel Island (Fig. 43). Most of these sightings were either close to or in pan ice. The whales generally either dove for long periods with little travelling, or remained quiescent at the surface (Würsig et al. 1983). The only sightings within the main industrial area were of two whales in water <10 m deep south of Tarsiut. Limited coverage north of the industrial area found few whales, and the only ones found to the east were near Cape Bathurst (Fig. 43). Whether there were many bowheads beyond the edge of the continental shelf to the north and northeast is unknown.

Many whales were rather close to shore in mid August, but almost all of these were NE of Herschel Island or Cape Bathurst, where deep water occurs near shore (Fig. 46). Few whales were in water <50 m deep. Although very few whales were in the main industrial area, whales near Herschel Island were exposed to noise from seismic exploration farther offshore (Fig. 45). Seismic noise levels as high as 133 dB//1 μPa--up to 40 dB above ambient--were recorded near whales off Herschel Island on 16 and 18 August (Greene 1983; Richardson et al. 1983b).

Distributions were very different in mid August 1980, 1981 and 1982. In 1980, whales were abundant in shallow water off the eastern Delta and western Tuk Peninsula. In 1981 they were not found there, but were widespread farther to the NW, N and NE. In 1982, they were most abundant near Herschel Island.

In **late August 1982**, there were still many bowheads near Herschel Island but others were found from west of Herschel Island to Cape Bathurst (Figs. 47, 51). Some additional whales were found in the Alaskan Beaufort Sea at this time (Ljungblad, pers. comm.). Whales were particularly numerous at the steep shelf break north of the Mackenzie Delta; there the water depth increases from 100 m to 500 m within a few kilometres (Fig. 46). This is the same area where bowheads were most abundant in early August 1981. A few of the 1982 sightings were within the main industrial area, but whales were much less frequent there than near Herschel Island and on parts of the outer shelf (Figs. 47, 51).

The results in Figure 51 are from the systematic survey of Harwood and Ford (1983). Their westernmost 14 transects were surveyed on 18-19 August, and the remainder on 22-24 August. They conservatively estimated that there were at least 1224 whales in the parts of the Yukon zone that they surveyed, 256 in the Delta zone, and 459 in the Tuk Peninsula zone. These estimates are conservative because the northern parts of each zone (as defined by Davis et al. 1982) were not sampled and because correction for missed animals was only partial. Also, the correction factor for percent of time below surface was based on behavioral observations in 1981, not 1982.

Distribution in late August was generally similar in 1982 to that in 1981, although more 'clumped'. Distribution in late August of 1980 was very different, with many whales being in shallow water off the eastern Mackenzie Delta and particularly off the western Tuk Peninsula.

In **early September 1982,** bowheads still were abundant off Herschel Island, but none were seen during our limited non-systematic coverage elsewhere (Fig. 53; from Davis et al. 1983). Ljungblad et al. (in prep.) saw a few whales northwest of Herschel Island (Fig. 53). On 5-13 September, Harwood and Ford (1983) conducted another systematic survey from west of Herschel Island to the eastern end of the Tuk Peninsula and north at least to the 100 m contour (Fig. 52). They found many whales NE of Herschel Island, mainly between the 50 and 200 m depth contours, and smaller numbers NW of Herschel Island. Farther east, there were only a few scattered sightings. However, there was no coverage beyond the shelf break in the Delta or Tuk Peninsula zones. Harwood and Ford estimated, again conservatively, that a least 1112 whales were in the surveyed parts of the Yukon zone, 163 in the Delta zone, and 115 in the Tuk Peninsula zone.

Very few whales were in the area of drilling and island construction during early September. However, the areas of greatest whale abundance, near Herschel Island, were probably ensonified by seismic noise (Fig. 55), as they definitely had been during mid August.

The one consistent feature of distribution in early September of 1980-82 was the occurrence of whales off Herschel Island. Bowheads seemed to be especially numerous there in 1982. Few were found off the Delta and Tuk Peninsula at this time in 1982, whereas in 1981 there were many, including some not far offshore from the Tuk Peninsula. Bowheads were also more abundant far off the Tuk Peninsula in early September 1980 than in 1982.

Bowhead Distribution before 1980

Before 1980, no studies directed specifically at bowheads were conducted in the Canadian Beaufort Sea. The very limited information available from previous years came from (1) the period of commercial whaling (1890-1910), (2) opportunistic observations during recent studies of topics aside from bowheads, and (3) reports by industry personnel working offshore. Sightings during summers up to 1978 are documented by Fraker et al. (1978) and Fraker and Bockstoce (1980). Sightings during the summer of 1979 are described by Fraker and Fraker (1979). In this section we summarize only the information that can be compared with the more comprehensive results from 1980-82.

The only large scale summer survey of the eastern Beaufort Sea done before 1980 was in 1974. That study by Renewable Resources Consulting Services Ltd. for the Canadian Wildlife Service was designed to survey waterbirds. Hence the aircraft flew at only 45 m a.s.l. (Searing et al. 1975). Despite repeated and extensive offshore coverage each month, very few bowheads were recorded--only three in July and three in August; slightly more in May and June (Fraker et al. 1978).

The scarcity of bowhead sightings during the 1974 surveys was doubtless partly attributable to the low survey altitude and the fact that birds were of primary interest. However, bowheads have often been found during low altitude surveys for birds in the eastern Canadian arctic (Davis and Koski

1980). The extremely heavy ice conditions in the eastern Beaufort in 1974 were probably a factor in reducing detectability of bowheads during the surveys, and perhaps also affected bowhead distribution. Whatever the explanation, sightings were too scarce to document bowhead distribution that year.

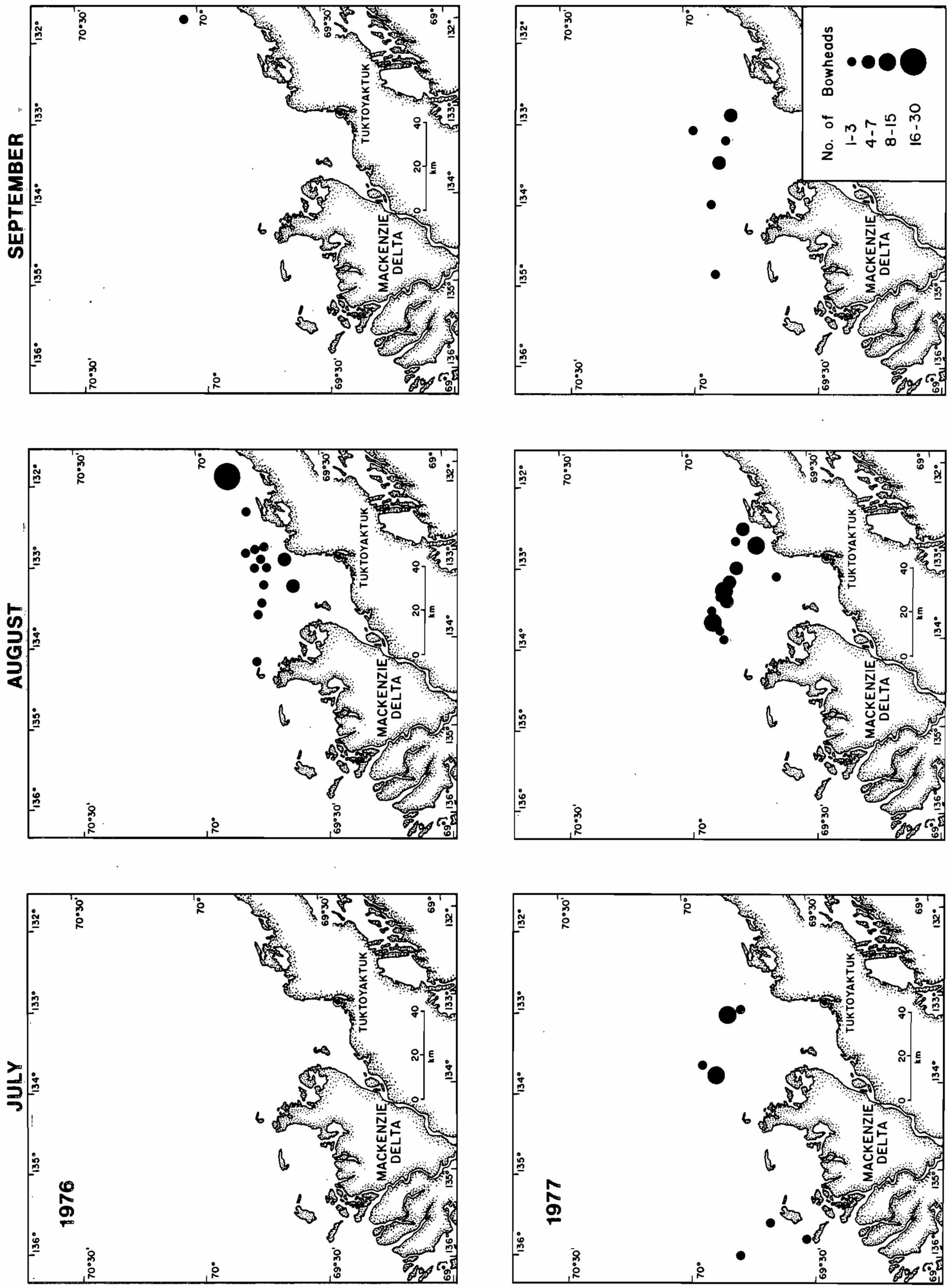
The area of shallow water off the eastern part of the Mackenzie Delta and western Tuktoyaktuk Peninsula is the one part of the Canadian Beaufort Sea where there has been some study of bowheads each year since 1976. In 1976, many bowheads were seen in water <15 m deep during the first half of August, with a few others later (Table 2; Fig. 56; Fraker 1977a). About 35-45 were seen on 10 August alone. In the previous four years of study in the same area, no bowheads were reported.

Table 2. Bowhead sightings off the eastern Mackenzie Delta and western Tuktoyaktuk Peninsula in the summers of 1976-80[a].

	Incidental Sightings[b]		Systematic Offshore Surveys, 1-15 Aug		Dates Observed	
Year	# of Sightings	# of Bowheads	# of Bowheads	Density (/1000 km^2)	First	Last
1976	15	46	-	-	3 Aug	16 Sept
1977	26	98	-	-	26 July	17 Sept
1978	5	58	1[c]	0.5	26 July	14 Sept
1979	1	6	1	0.5	8 Aug	9 Sept
1980	18	136	139	41.0	2 Aug	11 Sept

[a] Sources: Fraker (1977a,b, 1978), Fraker et al. (1978, 1982), Fraker and Fraker (1979), Fraker and Bockstoce (1980), and P. Norton (unpubl.).
[b] Sightings by industry personnel and biologists, excluding sightings during the systematic offshore surveys and during specific studies of bowheads.
[c] Plus sightings totalling 4 whales on 26 July 1978.

Similarly in 1977, there were 26 sightings totalling almost 100 bowheads in water <15 m deep off the Delta and western Tuk Peninsula between 26 July and 17 September (Table 2; Fig. 56; Fraker 1977b). Many of these sightings were from vessels that were travelling farther offshore than was common in previous years. Opportunities for observations thus were increased. Nonetheless, the sightings show that numerous whales did occur in the shallow waters of the Mackenzie estuary in 1976 and 1977.


JULY
AUGUST
SEPTEMBER
1976
1977
MACKENZIE DELTA
TUKTOYAKTUK
0 20 40 km
No. of Bowheads
1-3
4-7
8-15
16-30
132°
133°
134°
135°
136°
69°
69°30'
70°
70°30'

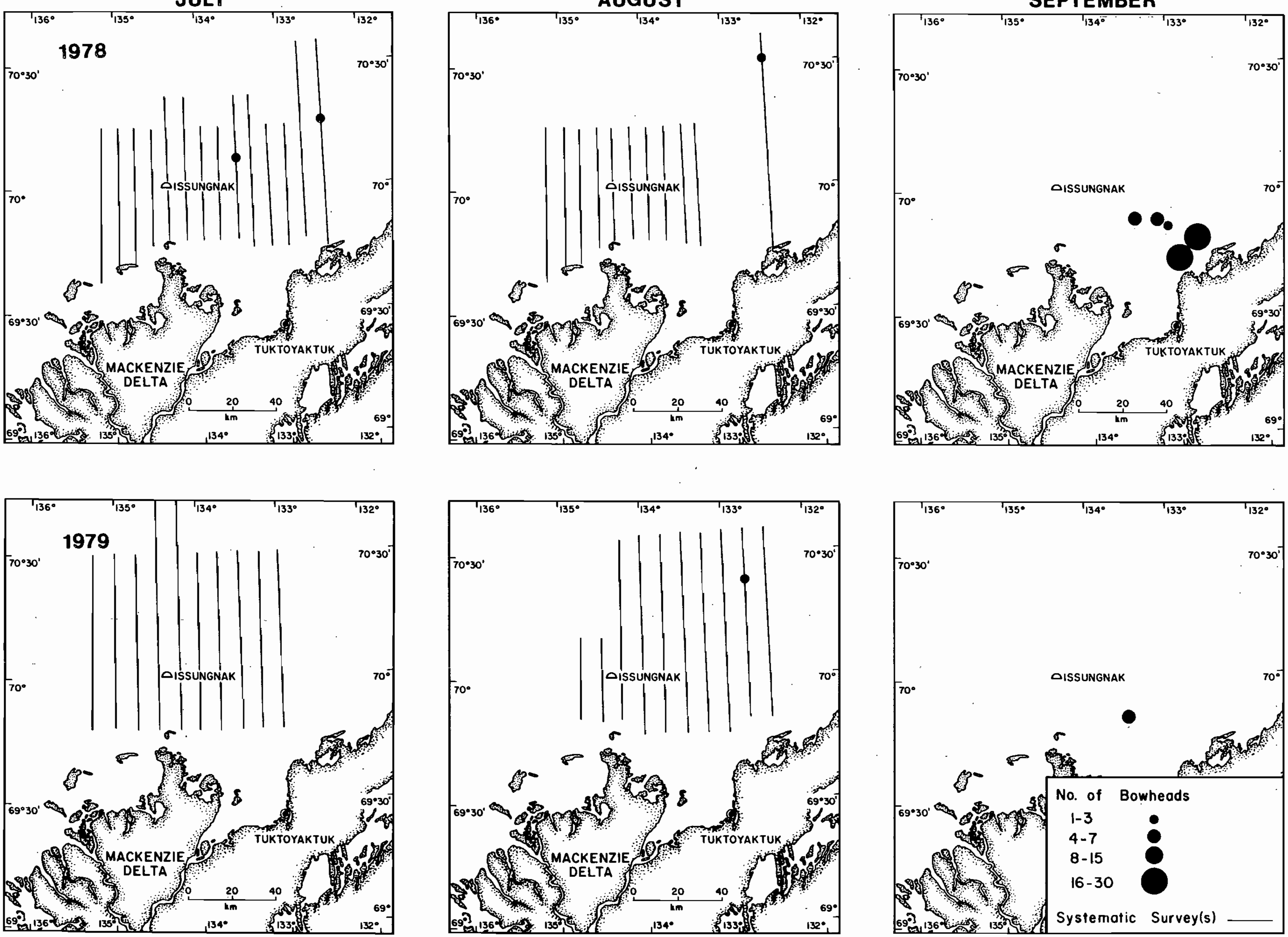


FIGURE 56. Bowhead sightings off the eastern Mackenzie Delta and western Tuktoyaktuk Peninsula in the summers of 1976-1979. Sources as for Table 2. There were no systematic surveys in 1976-77. Each survey line shown on maps for 1978-79 was covered once or twice.

In 1978, there were fewer incidental sightings in the shallow waters off the Delta and western Tuk Peninsula--only five sightings of a total of 58 whales. All were seen from 7 to 14 September in water 11-18 m deep (Table 2; Fig. 56; Fraker 1978). Opportunities for observation in August 1978 were similar to those in 1977, when many whales were seen. Also, from 26 July to 8 August 1978, Fraker conducted four systematic and intensive aerial surveys out to about the 50-60 m isobath off the eastern Delta. Only five whales (0.9 per 1000 km^2) were found, all near the 50 m isobath (Fig. 56). Only one of these was seen during the two August surveys (0.5 per 1000 km^2). Bowheads clearly did not move into shallow water off the eastern Mackenzie Delta as early in 1978 as in 1976 or 1977.

Similarly, in 1979, only one bowhead was seen during three systematic surveys off the Delta on 21 July-8 August (Fig. 56; Fraker and Fraker 1979). These surveys were of about the same area as in 1978. The uncorrected density was 0.3 per 1000 km^2, or 0.5 per 1000 km^2 during the two August surveys. Industry personnel reported only one sighting in 1979--six or more bowheads in 12 m of water on 9 September (Fraker and Fraker 1979). Much of the industry activity was at Issungnak island, which was under construction in 18 m of water off the Delta.

In marked contrast to the 1978-79 results, large numbers of bowheads were in shallow waters around Issungnak in the first half of August 1980 (e.g., Figs. 2, 6). Five systematic surveys there on 5-12 August detected an uncorrected density of 41 bowheads per 1000 km^2 (from data in Fraker et al. 1982). Industry personnel in the Issungnak area reported 18 sightings of a total of at least 136 bowheads.

In summary, studies since 1976 show that the abundance of whales in shallow waters off the eastern Mackenzie Delta has varied markedly from year to year. Bowheads were numerous there in August 1976 and 1977, infrequent until 7 September in 1978, and infrequent in 1979 (Fig. 56). They were abundant there in 1980, infrequent in 1981 (although more common in mid August 1981 off the central Delta), and rare or absent in 1982.

DISCUSSION

The preceding material shows that the distribution of bowheads in the eastern Beaufort Sea varies greatly both within and between summers. Nonetheless, some consistent patterns are evident. These patterns are summarized here before we consider the possible relationships of changes in distribution to industrial activity and other factors.

Seasonal and Annual Trends in Distribution

Few bowheads occur in the shallow waters off the Mackenzie Delta and Tuktoyaktuk Peninsula before 1 August, based on our systematic results from 1981 and the scarcity of incidental sightings in other years. In late July 1981, some bowheads were in Amundsen Gulf, some well to the west off the Yukon coast, and others far to the north of the Delta, near the edge of the continental shelf. The majority of the population was not detected and was believed to be in the pack ice far to the north.

These results are only partly consistent with sightings by commercial whalers about 80 years ago (Fraker and Bockstoce 1980). Bowheads were then found in the extreme eastern Beaufort Sea, e.g. off Cape Bathurst, in early summer. Whales were first found on the outer part of the shelf north of the Delta and Tuktoyaktuk Peninsula in early August. Fraker and Bockstoce suggested that these whales were migrating west. However, many might have been migrating south from deeper, ice-covered waters; most of the population was apparently in those ice-covered waters in late July 1981. The whalers' logbooks provided no evidence about whales either far to the north or off the Yukon coast in early summer, when these areas usually were inaccessible to whalers because of ice.

In August, many bowheads move into shallower waters in the southeastern Beaufort Sea. However, the timing of this movement and the locations of concentrations vary from year to year. In 1980, many whales appeared in shallow waters (15-35 m) off the Mackenzie Delta around 2 August. This concentration did not occur in early August of 1981 or 1982. Fragmentary evidence from 1976-1979 indicates that numerous whales appeared in shallow waters off the Delta at about this time in 1976 and 1977, but not in 1978 or 1979. There is no information about the direction from which the whales arrived in 1976, 1977 or 1980.

Figures 57 and 58 summarize what is known about bowhead distribution in the eastern Beaufort Sea in early and late August of 1980, 1981 and 1982. We have categorized the region into areas with zero, low, moderate and high apparent densities of whales. Because of the widely varying survey procedures, actual densities often were not known. Hence, the categorization has been done subjectively from the 1-10 August and 22-31 August sighting maps in the Results. Areas with widely separated sightings of 1-3 whales were designated as low density areas. Those with frequent sightings of 1-3 whales were treated as moderate density. Areas with sightings of large groups of whales were treated as high density.

In early August of 1981 and 1982, the largest known concentrations of bowheads were farther offshore than in 1980 (Fig. 57). In 1981, the largest concentration was near the shelf break about 125 km offshore from the Delta, although whales were distributed widely at lesser densities on the outer part of the shelf. The appearance of whales along most of the outer shelf off the Delta and Tuktoyaktuk Peninsula in mid August 1981 (Fig. 29) suggests that the whales were moving more or less south on a broad front. In early August 1982, whales were not as widely distributed; the only area with sightings was on the outer part of the shelf off the western Delta and the Yukon coast. Many of the whales off the Delta were moving west, and some whales were present on the outer shelf in the Alaskan Beaufort Sea (Ljungblad pers. comm.).

In each of the three years studied in detail, the area of peak whale concentration was closer to shore in mid August than in early August. In 1980 the shift was slight, since the whales were already in shallow water in early August, but in 1981 and especially 1982 the shift was more dramatic. In mid August 1982, the only large concentration of bowheads within the eastern Beaufort Sea was near Herschel Island, off the Yukon coast. In 1981, the water depth in the areas of peak concentration was also considerably less in mid than in early August. In 1982, the difference in water depths was not large because the area off Herschel Island where whales concentrated is quite deep. The area of peak concentration in mid August was farther west (and north) in 1981 than in 1980, and still farther west in 1982.

Distributions in late August were related to those in early and mid August, and again were quite different in the three years. In 1980, there was a large area of concentration in shallow and deeper waters off the Tuktoyaktuk Peninsula and eastern Delta (Fig. 58A). The center of distribution had shifted eastward relative to that earlier in the month. Few whales were found farther west, although survey coverage there was meagre. In 1981, the areas of greatest abundance were in shallow waters off the central Delta and in deeper waters near the shelf break off the eastern Yukon, Delta and, to a greater extent than in mid August, the Tuktoyaktuk Peninsula (Fig. 58B). In late August 1982, whales were still concentrated near Herschel Island, but there were also concentrations near the steep shelf break off the Delta and, to a lesser extent, off the eastern Tuktoyaktuk Peninsula (Fig. 58C).

In each of these three years, bowheads were more broadly distributed in late than in mid August. In 1980, the concentration of whales extended farther eastward and perhaps farther offshore in late August. In 1981, numbers increased in the Tuktoyaktuk Peninsula zone in late August and remained high off the Delta. Furthermore, within the Delta zone, the whales were more uniformly distributed on the outer shelf in late than in mid August. In 1982, the great majority of sightings in mid August were off Herschel Island despite broad survey coverage elsewhere; in late August the Herschel Island area remained important, but whales also were numerous well offshore in the Delta and the Tuktoyaktuk Peninsula zones.

Distributions differed less among years in early September than in August. Nonetheless, there were again considerable year to year differences. In 1980, numerous whales remained off the Tuktoyaktuk Peninsula, although farther offshore than in August (Fig. 14). Also, whales appeared close to shore off Herschel Island. In 1981, whales moved closer to shore off the Tuktoyaktuk Peninsula in early September than they had been in August (Fig. 38). There were many whales near Herschel Island, and low

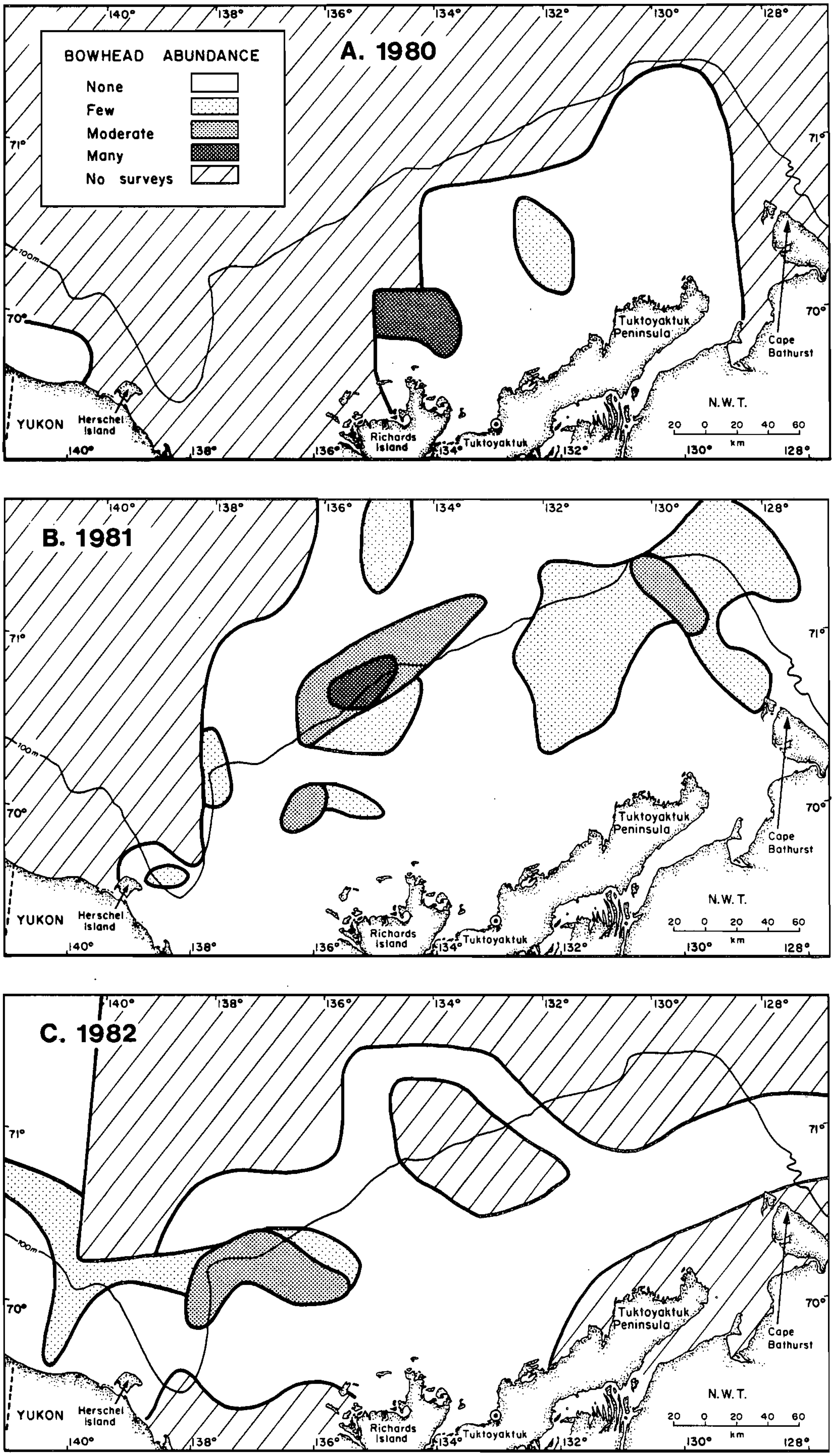


FIGURE 57. Distribution of bowheads in early August of 1980, 1981 and 1982.

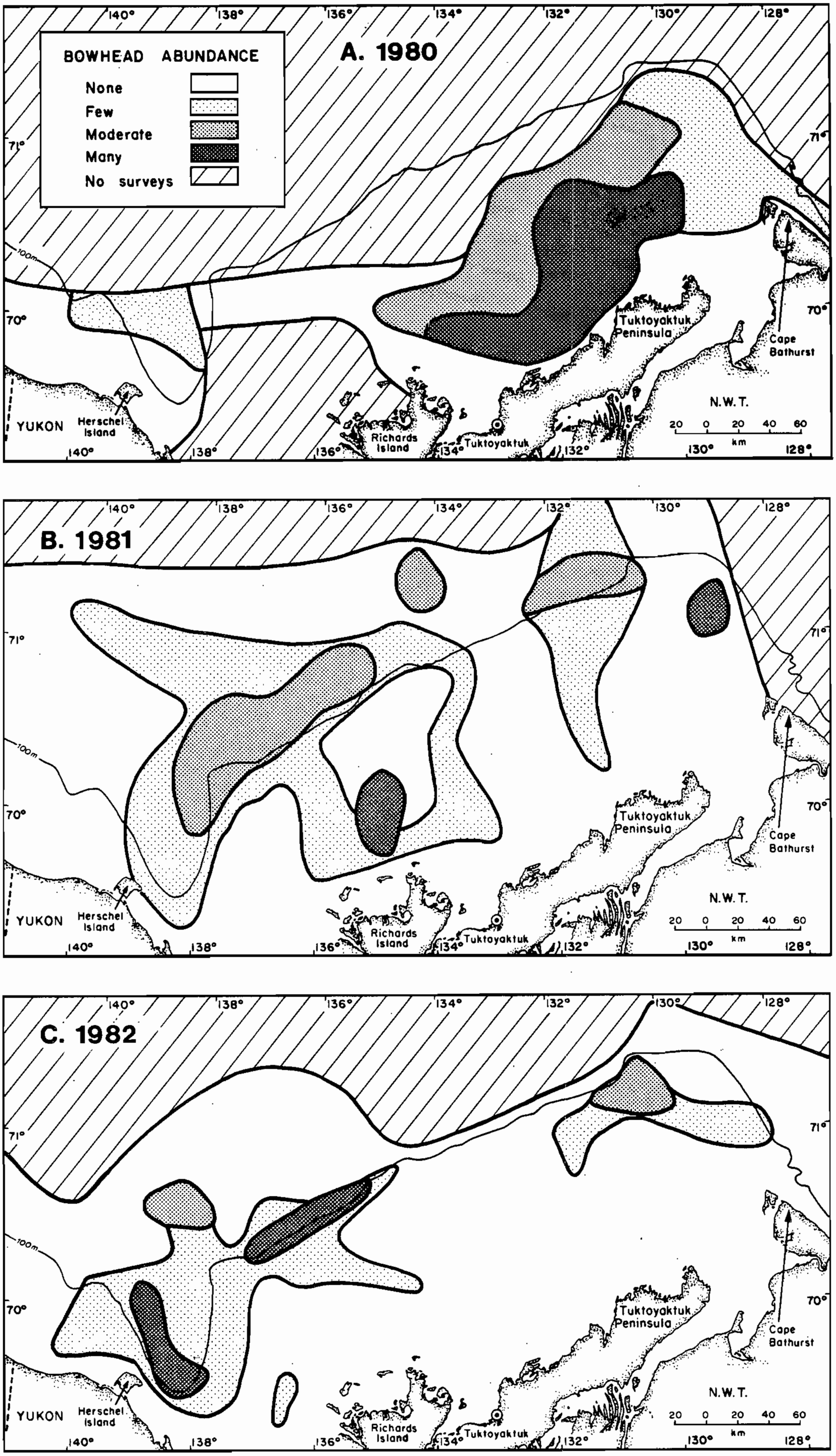


FIGURE 58. Distribution of bowheads in late August of 1980, 1981 and 1982.

densities off the Delta and near Cape Bathurst. In 1982, the largest concentration was near and north of Herschel Island, but there were a few sightings off the Delta and Tuktoyaktuk Peninsula.

One notable feature of bowhead distribution during early September was the consistent occurrence of whales as far east as the Tuktoyaktuk Peninsula, and sometimes to Cape Bathurst (Fig. 14, 38, 52). Although bowheads begin to appear in the Alaskan Beaufort Sea during or before early September (Ljungblad et al. 1982; pers. comm.), many remain in Canadian waters in early and mid September. Davis et al. (1982) estimated that over 2500 bowheads were in the Canadian Beaufort Sea as late as 7-14 September in 1981.

Bowheads have been seen off Herschel Island in early September of 1980-82, and were there in especially large numbers in mid and late August 1982. Bowheads also were found near Herschel Island in late summer and early autumn 70-90 years ago (Fraker and Bockstoce 1980). During the 1970's, bowheads were often seen along the Yukon coast southeast of Herschel Island in late summer, but in 1980-82 there were many fewer bowheads there than off Herschel Island.

Distribution in Relation to Industrial Activities

Behavioral studies show that bowheads swim away from approaching boats and sometimes dive as aircraft fly low overhead. However, bowhead behavior seems to return to normal after the boat moves away or the aircraft ceases flying directly overhead (Fraker et al. 1982; Richardson et al. 1983b). There is also limited evidence of avoidance of drillship noise when it first begins. On the other hand, bowheads have been seen within a few kilometres of operating drillships on several occasions. Bowheads have also been seen near dredging operations and in areas ensonified by strong seismic noise; these whales were not swimming away from the noise sources, although behavior seems to be altered subtly in the presence of seismic noise on some occasions.

Although short-term reactions to offshore oil exploration seem to be brief or absent, the behavioral studies cannot determine whether fewer whales determine whether industrial operations result in a reduced tendency to return to the area in subsequent years. Large-scale survey results collected over a number of years provide the only straightforward way to address these questions.

In Figure 59, the primary areas of offshore industrial activity in mid and late August of each year are superimposed on the maps summarizing bowhead distribution in late August. The boundaries of the industrial areas are based on the industrial activity maps in the Results. Industrial activities have been separated into two types: (1) site specific activities such as dredging, island construction and drilling, along with vessel and helicopter traffic in support of those activities, and (2) offshore seismic exploration. The area with activities of type 1 is referred to here as the 'main industrial area'.

Bowheads and the Main Industrial Area

In 1980, large numbers of bowheads were around the island construction site at Issungnak in early and mid August (Fig. 2, 6). Issungnak was in 18 m of water off the central Mackenzie Delta. Vessel and helicopter traffic to the four drillships farther offshore also passed through or near that area of whale concentration. By late August, most whales were somewhat east of the offshore construction and drilling sites; however, the western edge of the whale concentration was near Issungnak (Fig. 59A). In general, the only known concentration of bowheads in August 1980 was well within the area of most intense industrial activities for much of the month, and overlapped that area for the rest of the month.

In 1981, drilling, dredging and the associated vessel and helicopter traffic extended farther east and west but less far offshore. Most bowheads remained north or west of the area of intense industrial activity (Fig. 59B). The only significant numbers of whales found near industrial sites were off the central and western Delta in mid and late August. On most days, these latter whales were 10 km or more to the west of the artificial island and drillship in the Issungnak area.

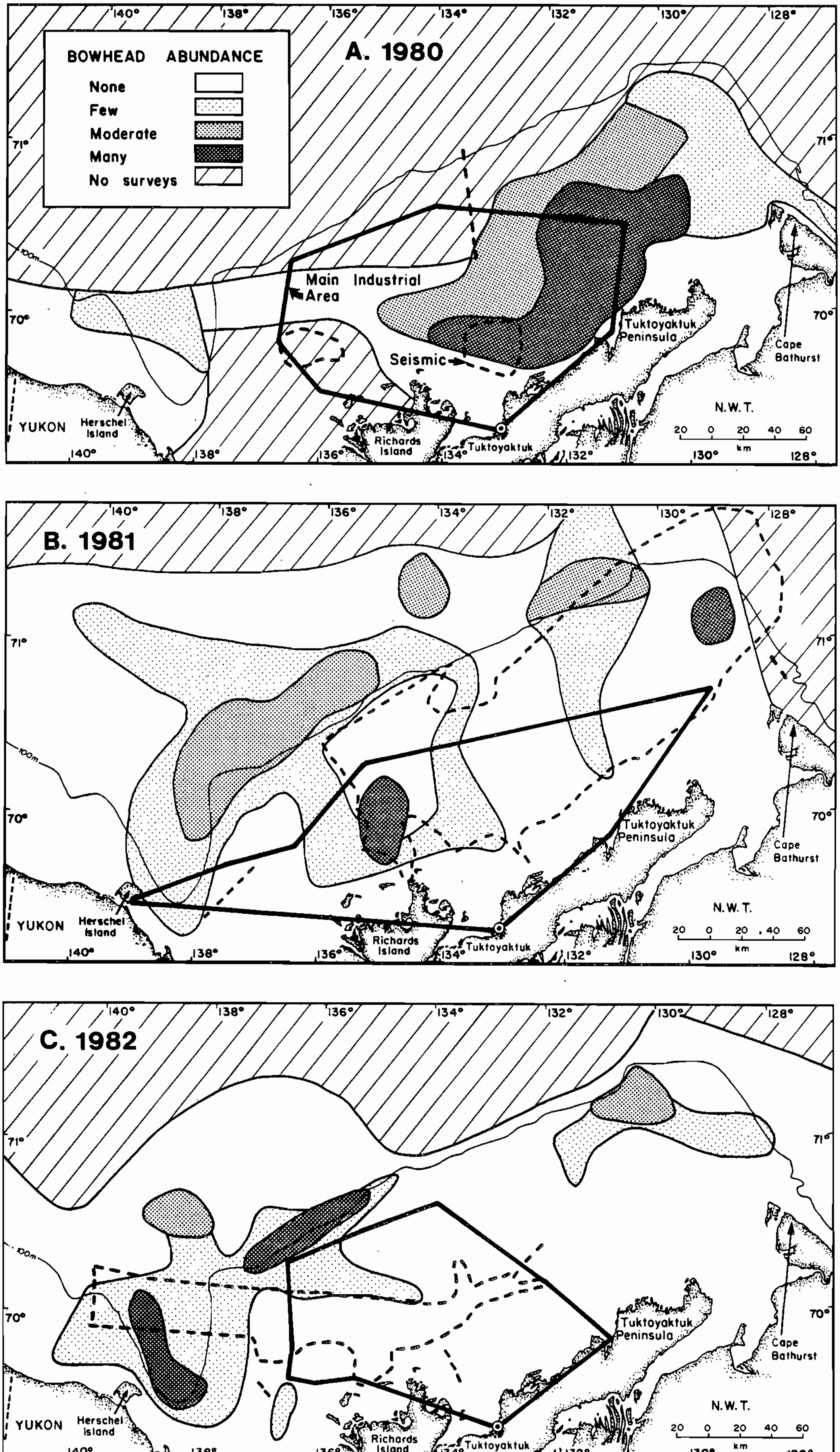


FIGURE 59. Distribution of bowheads in late August of 1980, 1981 and 1982 in relation to the areas of industrial activity in mid and late August.

In 1982, there was even less overlap between whale distribution and the area of intense offshore exploration (Fig. 59C). There were very few sightings within the main industrial area at any time during the summer.

Thus, over the 1980-82 period there was a strong tendency for bowhead distribution to overlap progressively less with the area of offshore dredging, construction and drilling.

In interpreting this trend, it is important to remember that offshore oil exploration had been underway in the same general area for several years before 1980. Esso's island construction program moved into deeper water off the central Mackenzie Delta around 1976, with the construction of Isserk in 13 m of water. Construction first extended out to a water depth of 18 m in 1978, when construction of Issungnak began. Drillships have operated in the area each summer since 1976. Thus, the appearance of many whales within the main industrial area in 1980 occurred some 4 years after offshore operations in that area became intensive.

It is also important to note that many whales were seen in shallow water off the eastern Delta and western Tuktoyaktuk Peninsula in early August of 1976 and 1977 but not in 1978 or 1979 (Fig. 56). In the absence of systematic surveys during 1976-77, it is uncertain how similar the distribution then was to that in 1980. In any case, far fewer whales were seen there during repeated systematic surveys in late July-early August 1978 and 1979 (Fig. 56). Hence, numbers of whales off the eastern Delta in early August were high in 2 of 4 years before 1980. Within that area, offshore industrial activity has been intense since 1976.

Thus, bowheads were numerous in the part of the industrial area off the eastern Mackenzie Delta in early August of 1976, 1977 and 1980, but not in 1978, 1979, 1981 and 1982. Given the presence of many whales in 1980, there is no clear trend for decreasing numbers of whales after the onset of intense industrial activity in this one small area. Unfortunately, no distributional data were collected in other offshore areas before 1980. Without such data, it is unknown whether the distributions in 1981 and 1982 were unusual.

If a distribution pattern similar to that in 1980 is found in the next year or so, then it will be much clearer that oil exploration is not the main factor responsible for the year to year variations in distribution. If bowheads remain far offshore in future years, then the contrast with 1976, 1977 and 1980 will become more striking, and a connection with industrial activity will be more probable.

Bowheads and Areas of Seismic Exploration

From 1980 to 1982, there has been progressively less whale use of areas with dredging, island construction and drilling, but there has been no similar trend for decreased use of areas with seismic exploration.

Seismic exploration occurred in the shallow areas off the eastern Mackenzie Delta every year from 1971 to 1982, including 1976, 1977 and 1980 when many bowheads were present. The 'Arctic Surveyor' operated north of Kugmallit Bay throughout August 1980 (Fig. 59A). Bowheads were seen as close as 8 km and 13 km from the ship on two dates (Richardson et al. 1983b). In early August, when bowheads first moved into the Issungnak area, another seismic vessel was operating just to the north and northeast (Fig. 4). In early September, whales far offshore from the Tuktoyaktuk Peninsula were probably exposed to noise from seismic exploration just to the south (Fig. 16).

In August 1981, there was widespread seismic exploration north of the Mackenzie Delta and, from mid-month on, the Tuktoyaktuk Peninsula. The concentrations of whales in shallow water off the Delta and in deeper water off the eastern Tuktoyaktuk Peninsula in late August were definitely exposed to strong seismic sounds on some days; some whales off the Delta in early August were also exposed (Fig. 59B; Richardson et al. 1983b). In mid September, a concentration of whales off the western Yukon was exposed to seismic noise (Ljungblad et al. 1982).

In 1982, bowheads that were travelling west off the western Mackenzie Delta in early August were sometimes exposed to seismic noise, as were the large numbers that concentrated off Herschel Island in mid August (Fig. 59C;

Richardson et al. 1983b). There was probably continued exposure in the latter area in early September (Fig. 55).

These observations show that many bowheads continued to encounter seismic exploration in 1981 and 1982, despite the fact that few whales entered the main area of drilling, dredging, etc, in those years. The occurrence of many whales off Kugmallit Bay in 1976, 1977 and particularly 1980 shows that an area of intensive seismic exploration is not necessarily avoided in subsequent years. This is corroborated by the recurrence of whales off Tuktoyaktuk Peninsula in late August and early September 1981 and 1982 despite seismic exploration there at those times in 1980 and 1981.

These observations suggest that seismic exploration has not caused large scale abandonment of parts of the summer range. However, nothing is known about the recurrence of specific individual whales at places where they were exposed to seismic noise in previous years. It is possible that the whales seen off Kugmallit Bay in 1980 and off the Tuktoyaktuk Peninsula in late summer of 1981-82 were not the same ones that were there in previous years. The recent development of techniques for recognizing individual bowheads (Davis et al. 1982, 1983) provides a method by which this question can be addressed.

Natural Factors Affecting Bowhead Distribution

The predominant activity of bowheads in summer is feeding. Analyses of food abundance in relation to energy demands show that bowheads must concentrate their feeding in areas of above-average plankton abundance (Brodie 1981; Griffiths and Buchanan 1982). The latter authors have demonstrated that copepod abundance in areas with bowheads tends to exceed that in other areas nearby. Copepods and euphausiids are apparently the main food items for bowheads in the Alaskan Beaufort Sea during early autumn (Lowry and Burns 1980), and presumably are also important to bowheads in summer. Thus, factors affecting the availability of these and other food organisms in the eastern Beaufort Sea probably have a strong influence on the distribution of bowheads.

There has been little quantitative study of zooplankton in the Canadian Beaufort Sea, and no specific study of year-to-year variations in its abundance in different parts of the area. Thus, it is impossible to assess whether the observed year-to-year variations in bowhead distribution have any connection with variations in zooplankton abundance.

Mackenzie River Influence. -- Geographic and temporal variations in zooplankton abundance are especially likely in the nearshore area most strongly influenced by freshwater input from the Mackenzie River. The river water affects salinity, temperature, turbidity and nutrient content of the water over a wide area of the southeastern Beaufort Sea. Each of these can affect zooplankton abundance. In general, zooplankton biomass is much lower in brackish areas of the Mackenzie estuary than farther offshore (Grainger 1975; Griffiths and Buchanan 1982). At particular locations in the southeastern Beaufort Sea, characteristics of the water mass, and probably of the zooplankton, vary dramatically because of seasonal variation in volume of flow from the Mackenzie. Shorter-term variations in salinity and temperature can occur because changes in wind cause different patterns of water movement off the Delta (Herlinveaux and de Lange Boom 1975; MacNeill and Garrett 1975).

Year-to-year differences in river output probably also affect the size of the area influenced by freshwater outflow. Interestingly, river flow increased progressively from 1980 to 1981 to 1982, coincident with the trend for decreasing numbers of bowheads in the area off the Mackenzie Delta. Whether there was any causal connection mediated by zooplankton abundance is unknown.

Shelf Break. -- Over the 1980-82 period, concentrations of bowheads have been seen in water depths ranging from <20 m to several hundred metres. Sometimes most bowheads were believed to be in deep waters off the shelf because of their scarcity in surveyed shelf areas. It is now clear that bowheads do not concentrate in waters <50-100 m deep as regularly as suggested by Fraker and Bockstoce (1980).

Despite this variability, water depth apparently is another factor that can influence bowhead distribution. On several occasions in 1981-82, bowheads concentrated near the 'shelf break', where water depths increase especially rapidly. Alignment of bowheads along the shelf break was evident in August 1981 (particularly in early August) and in late August 1982 (e.g., Fig. 21, 29, 47). Davis et al. (1982) suggested that upwelling or some other factor leading to enhanced plankton abundance may be responsible for the tendency of summering bowheads to concentrate at the shelf break.

Ice. -- The role of ice conditions in determining the summer distribution of bowheads is not clear. In late spring when bowheads first arrive in the eastern Beaufort, extensive open water is usually restricted to the easternmost part of the Beaufort Sea: off the west coast of Banks Island, in western Amundsen Gulf, and parallel to the Tuktoyaktuk Peninsula (e.g., Fraker 1979). Many bowheads travel eastward through leads and cracks in the pack ice to these open water areas (Fraker 1979; Fraker and Bockstoce 1980).

Whether all the Western Arctic bowheads travel far east to the open water is unknown. If they do, then it is clear that a large proportion of them must return westward into the pack ice in mid summer of at least some years, such as 1981. However, it is probable that many whales remain in the pack ice in the Beaufort Sea throughout early summer.

The area of open water in the eastern and southeastern Beaufort Sea tends to expand westward and northward as the summer progresses. However, even in late summer the northern and western parts of the Canadian Beaufort usually contain considerable pan ice (see maps in Results). Many of the whales seen in late summer of 1981 and 1982 were near or in ice. The concentration of whales off Herschel Island in 1982 formed in the absence of ice, but remained there after extensive pack ice blew into the area around 16 August.

The southern edge of the pack ice was only a few kilometres north of the concentration of whales along the shelf break in early August 1981. Thus, ice as well as the sharp change in water depth may have influenced the distribution of whales or their food organisms. It is known that upwelling sometimes occurs along pack ice edges (Buckley et al. 1979). However, there was little ice near the concentration of whales along the shelf break in late August 1982.

Clearly, the distribution of bowheads summering in the eastern Beaufort Sea may be influenced by several naturally varying factors aside from any influence of industrial activity. A further complication is that industrial activities may affect some of the natural factors. For example, hydroelectric developments far away on tributaries of the Mackenzie River are expected to produce significant changes in the flow of the river. This could, in turn, affect the locations of peak zooplankton abundance off the Delta. It is doubtful that the overall productivity of the area would be altered enough to affect bowheads. However, the distribution of that productivity might change enough to confound interpretation of the role of offshore oil exploration in affecting bowhead distribution.

At present, detailed data on bowhead distribution have been collected for only three years. This has been long enough to document pronounced year-to-year changes in bowhead distribution, but not long enough to allow a judgement about the role of offshore oil exploration in affecting that distribution. If studies over the next year or so show that bowheads return to the main industrial area as they did in 1980, then there will be strong evidence that oil exploration has not excluded bowheads from part of their range. The case will be especially strong if some of the recognizable individuals return to industrial areas where they have been seen in previous years. On the other hand, if a distribution similar to that seen in 1980 does not recur soon, then there will be increasing reason for concern about possible long-term effects of oil exploration on bowheads. In either case, a better understanding of the interrelated roles of river flow, wind, ice and upwelling in affecting plankton abundance and bowhead distribution may be necessary before firm conclusions about effects of industrial activity on bowhead distribution can be drawn.

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Many individuals and groups responded to our requests for information about industrial activities. These include the following:

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Bedford Institute of Oceanography:	Al Adams
Canadian Superior:	Ron Webster
Dome Petroleum Ltd.:	Tom Barton, Tom Edmunds, Muharrem Gajtani, Hugh Kelly, Vaughan Payne, Jean Plume, Gary Price, Richard Samson, Erwin Unger and John Ward.
Esso Resources Canada Ltd.:	Lucille Green, Ross Haynes, Arnie LaCroix, Wilf Picard, Mark Psutka, Ron Quaife and Al Stuart.
Geophysical Service Inc.:	Gary Bartlett, Karen Bottomly and Jack Stone.
Geoterrex Ltd.:	Rick Quinn
Gulf Canada Resources Inc.:	Jim McComiskey
Institute of Ocean Sciences:	Jim Vosburg
Northern Transportation Co. Ltd.:	Ken Hnatuik, Ed Yurkovich.

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