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BEHAVIOR OF BOWHEAD WHALES OF THE DAVIS STRAIT AND BERING/BEAUFORT STOCKS VS. REGIONAL DIFFERENCES IN HUMAN ACTIVITIES

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ABSTRACT

The Minerals Management Service funded a study to compare the behavior of bowhead whales in the western arctic (Bering/Chukchi/Beaufort stock) and in the eastern arctic (Davis Strait stock) to determine whether differences in behavior could be attributed to the presumed higher levels of human activities in the western arctic. The study was conducted in two phases. Phase 1 consisted of a quantitative examination of bowhead behavior in the two regions; it documented several statistically significant differences between the two stocks (see Richardson and Finley 1989 for the report on Phase 1). Phase 2 of the study consisted of a detailed evaluation of the levels of human activity and potential disturbance to which each stock was exposed. Phase 2 is the subject of the present report,

Human activity information was compiled for the areas occupied by the Davis Strait and Bering/Beaufort bowhead stocks in the various seasons when whales were present. These data were compiled for the 13 year period 1974-1986, a period that includes years with varying degrees of oil-industry activity in the eastern and western arctic. Based on these compilations, the relative exposures of the two stocks to several categories of human activities were assessed.

Subsistence-related vessel traffic occurs in both areas, but intense spring and autumn hunts for bowheads occur only in the Bering/Beaufort area. Although subsistence traffic not associated with bowheads may be somewhat higher in the Davis Strait area, the bowhead hunts in the Bering/Beaufort area during spring and autumn have considerably more potential to disturb bowheads. Those hunts are directed specifically at bowheads and they occur at times and places where much of the Bering/Beaufort stock is present.

Commercial fishing is most prevalent in the Davis Strait area where there was an average 2,002 vessel-days per year, equivalent to an average of 5.5 fishing vessels per day. This compares to virtually no commercial fishing in the range of the Bering/Beaufort stock when whales are present. However, most of the fishing activity in Davis Strait occurs in parts of the range that contain few if any whales and few bowheads are likely to be disturbed by commercial fishing vessels in the course of a year.

Marine seismic exploration was more common in the range of the Davis Strait stock during the first two years (1974-75) of the study period, but was much more common in the Bering/Beaufort area in the final 11 years. During the late summer period, direct comparisons of seismic levels in the two areas were possible. There was more than three times as much marine seismic exploration in the Bering/B eaufort area in late summer.

Relative levels of commercial vessel traffic (including offshore drilling) were much higher in the Bering/Beaufort area during the peak summer and autumn shipping seasons. Various indices of commercial vessel traffic during summer and autumn were 3-5 times higher in the Bering/Beaufort area than in the Davis Strait area. Furthermore, much of the Bering/Beaufort traffic occurs in important summering and autumn migration areas, whereas the vessel traffic is more widely distributed through the range of the Davis Strait stock, including many areas where few or no whales are usually present.

Three indices representing the amount of low-level air traffic were all higher in the Bering/Beaufort area than in the Davis Strait area. Although there are numerous coastal airstrips in the Davis Strait area, few airstrips occur where bowheads are common, and the probability of disturbance is low. In the Bering/Beaufort area three coastal airstrips are located where bowheads concentrate and disturbance is like] y. More than twice as many helicopters fly over Bering/B eaufort waters as over Davis Strait waters, and twice as many low-level survey flights have been conducted in the Bering/Beaufort area as in the Davis Strait area. .

The most intense, and potentially most disturbing, human activities are subsistence whaling, commercial vessel traffic, and marine seismic, These activities were much more prevalent in the Bering/Beaufort stock area than in the Davis Strait area. Quantification of some of these types of disturbance is incomplete or difficult. However, based on the numerical assessments of disturbance levels and the relative importance of each type, it was concluded that bowheads of the Bering/Beaufort stock have been subjected to at least 3 to 5 times as much disturbance as have bowheads of the Davis Strait stock.

When the results of Phases 1 and 2 were integrated, it was concluded that most of the differences in behavior between the two stocks were better explained by environmental or biological factors than by disturbance. However, in the case of bowheads migrating in autumn, there were statistically significant differences in behavior that tended to make bowheads of the Bering/Beaufort stock less conspicuous. This may have been a response to subsistence whaling in the Beaufort Sea.

There was no evidence that short-term responses to disturbance differed between the two stocks, but there are few data on short-term disturbance responses by the Davis Strait bowheads. If this lack of a difference in acute responsiveness is real, then there is no evidence that Bering/Beaufort bowheads have habituated to the higher levels of human activity.

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During Phase 2, many individuals and organizations assisted by providing information about human activities in Alaskan, Canadian and Greenland waters. M. Fabijan and N. Snow of the Inuvialuit Joint Secretariat supplied preliminary data from the Inuvialuit Harvest Study. Information about commercial fishing in the eastern arctic was provided by M. Allard of the Makivik Corporation, P. Johansen of the Greenland Environmental Research Institute and J. Cardoso of the Northwest Atlantic Fisheries Organization. J. Shaker, C. Smith and L. Watson of the Alaska Department of Fish and Game furnished fisheries statistics for western arctic waters.

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W. Koski of LGL Ltd. assisted in writing the Seasonal Distribution section and Ken Kertell of LGL Alaska Research Associates Inc. assisted in acquiring information on human activities in the western arctic. B. Griffen and K. Hester helped produce the report and S. Cutcliffe drafted *the* figures. Kerry Finley of K.J. Finley Ecological Research kindly reviewed some sections of *the* report. We thank all of these people and organizations for their efforts.

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INTRODUCTION

The Question of Long-term Cumulative Effects of Man on Bowheads

Over the past decade much concern has been expressed about the possible effects of offshore oil and gas exploration on various species of endangered baleen whales, including the bowhead whale. One area of concern has involved questions about the effects of underwater noise and other stimuli associated with industrial activity on the behavior of whales, As a result of this concern, the U.S. Department of the Interior and other agencies--governmental and industrial--have funded several major studies of the short-term behavioral reactions of baleen whales to industrial sounds. Major studies of this type have been done on bowhead whales, gray whales and humpback whales (see Richardson et *al.* 1991 for review). These studies have provided partial quantification of the relationships between noise levels and the short-term disturbance responses of baleen whales. However, these studies have provided little information about the significance of short-term behavioral responses to the long-term well-being of whale populations.

Studies of the possible long-term reactions of a population of whales to human activities are difficult to do, for a number of reasons. (1) A long-term study must, by definition, continue for an extended period, ideally a long period relative to the lifetimes of the animals involved. (2) Long-term experiments are generally impossible; one must rely on observations of whales in relation to year-to-year changes in actual human activities. (3) Often there are few or no quantitative data on whale activities prior to the start of the human activities that are suspected to affect the whales. (4) Data accumulate very slowly in such a study, in many cases at the rate of one observation per year, e.g., number of whales present each year. (5) It is very difficult to isolate the effects of one factor, such as human activity, from other factors, such as natural variations in the environment.

Most or all of these problems have been evident in previous attempts to evaluate long-term effects of human activities on whales, e.g., for

- minke and Baird's beaked whales off Japan (Nishiwaki and Sasao 1977),
- gray whales in lagoons along Baja California (Bryant et *al.* 1984),
- humpback whales in Hawaii (Norris and Reeves 1978; Glockner-Ferrari and Ferrari 1985; Bauer and Herman 1986),
- humpbacks in southeast Alaska (MMC 1979/80; Dean *et al*, 1985), and
- bowhead whales in the Canadian Beaufort Sea (Richardson *et al.* 1985a, 1987a).

Bowheads in the Beaufort Sea react, at least briefly, to underwater noise from ships, seismic exploration, marine construction, and drillships (Ljungblad et al. 1985, 1988; Richardson *et al.* 1985b,c, 1986, 1990a,b; LGL and Greeneridge 1987). On a longer-term basis, there are indications of reduced bowhead utilization in recent years of the part of the summer range where offshore oil exploration has been in progress over the past decade (Richardson *et al.* 1985a, 1987a). However, the degree of decrease in utilization of that area is controversial (Ward and Pessah 1988), partly because there were no systematic studies of bowhead distribution or behavior in summer before oil exploration began, It is possible that some or all of the year-to-year variability in use of the industrial area in recent years has been the result of responses by the whales to natural factors, especially the variable distribution of their food (ESL *et al.* 1986; Thomson *et al.* 1986; Bradstreet *et al.* 1987).

Rationale for Comparing Bering/Beaufort and Davis Strait Stocks

Questions about the long-term responses of endangered whales to human activities like offshore oil exploration are important despite the difficulties involved in designing and conducting effective studies. Recognizing this, MMS identified a new approach that might provide insight into the long-term, cumulative effects of human activity on bowhead whales,

The Western Arctic or Bering/Beaufort stock, in which the Alaska OCS Region of MMS has a particular interest, has been exposed to considerable human activity for a prolonged period. This human activity has included offshore oil exploration on part of the summering grounds since about 1976, additional oil exploration in Alaskan waters during the 1980s, other vessel traffic, and subsistence hunting pressure each spring and autumn. In contrast, the Eastern Arctic (= Davis Strait/B affin Bay) stock was believed to have been exposed to considerably less human activity in recent decades, Behavioral and other observations have been acquired during studies of both stocks in recent years. MMS recognized that a comparison of existing data on the behavior of these stocks might provide insight into the possible cumulative effects of human activities on bowhead behavior.

Bering/Beaufort Stock

The Bering/Beaufort stock was hunted commercially primarily during the middle and latter portions of the 19th century, with limited commercial whaling continuing until about 1919 (Bockstoce 1986; IWC in press). A subsistence harvest by Alaskan Eskimos continues to the present day. Nowadays, whales are hunted primarily from unmotorized boats deployed from the landfast ice edge in spring, and from motorboats in autumn.

The Bering/Beaufort stock is now by far the most numerous stock of bowheads. Estimates of its size have increased greatly over the past decade as censusing methods have improved (Zeh *et al. 1991a).* The most recent "best estimate" for the Western Arctic stock is 7,500 bowheads (IWC in press), with a wide range of uncertainty (95% confidence limit 6,400-9,200), There is some evidence that the size of the Bering/Beaufort stock is increasing (Zeh *et al. 1991* b).

Bering/Beaufort bowheads winter in the central and northwest Bering Sea, summer in the eastern Beaufort Sea and Amundsen Gulf, and migrate around western and northern Alaska in spring and autumn. Besides the subsistence hunting pressure during parts of the spring and autumn migration, the whales have become increasingly exposed to offshore oil exploration in various parts of their range. The south-central part of the summer range has been an area of much offshore drilling since 1976. Since the earl y 1980s there has been some drilling along the autumn migration route through the Alaskan Beaufort Sea. Drilling has also begun in the northeastern Chukchi Sea, across which bowheads travel in autumn. Extensive seismic exploration preceded and accompanies this offshore drilling. Oil exploration is also a possibility during the next few years in parts of the winter range in the Bering Sea. Besides the oil industry activities, there is also limited ship traffic near bowheads occupying various parts of the summer and autumn range.

Davis Strait Stock

The Western and Eastern Arctic stocks are effectively separated by a gap in bowhead distribution in the central and western part of the Canadian arctic archipelago. This area is usually covered by heavy multi-year ice for most if not all of the summer. There is no reliable evidence of exchange between these two stocks, although the possibility of exchange of a few individuals on rare occasions cannot be ruled out (Reeves et *al.* 1983a; Bockstoce 1986, p. 255).

In comparison with the Bering/Beaufort stock, the Davis Strait/Baffin Bay bowheads were hunted commercially for a much longer period, from the 16th to the early 20th centuries (de Jong 1978; Ross 1979, 1985; Mitchell and Reeves 1981; Aguilar 1986; Cumbaa 1986). Ross (1979) estimated that a minimum of over 28,000 bowheads were taken from the Davis Strait/B affin Bay stock based on available records for the period 1719-1911. This cumulative estimate of catch is known to substantially underestimate the actual harvest, but the total kill is not known. During the early years of commercial whaling the population sizes may have been about 11,000 animals for the Davis Strait/Baffin Bay group plus about 680 for the Hudson Bay group, with considerable uncertainty (Mitchell and Reeves 198 1). By the early 20th century both groups were almost extinct.

In contrast to the Bering/Beaufort stock, the Davis Strait/Baffin Bay group has not recovered to any significant degree. At present, it apparently consists of no more than a few hundred animals. The most recent data suggest a population size of at least 200-300 individuals, excluding the Hudson Bay animals (Finley *et al.* 1986; Finley 1987, 1990). Although there has been no routine or authorized subsistence harvest of Davis Strait bowheads since the end of commercial whaling about 80 years ago, bowheads are killed by Inuit on rare occasions. Mitchell and Reeves (1982) have speculated that, given the very small stock size, this occasional hunting pressure may be a significant factor in preventing population recovery. Predation by killer whales also may be a significant source of mortality (Mitchell and Reeves 1982; Finley et *al.* 1986; Finley 1987, 1990).

The remnant Davis Strait stock presently winters in its historical wintering range in the pack ice near the ice edge in Davis Strait and perhaps Hudson Strait (Fig. 1; McLaren and Davis 1982, 198 3; Born and Heide-Jørgensen 1983). The winter range of the Davis Strait stock is somewhat uncertain because of the unknown degree of segregation of those whales from the Hudson Bay whales, some of which seem to winter at least as far east as eastern Hudson Strait (Finley *et al.* 1982; Reeves and Mitchell in press).

The whales migrate northwest through Baffin Bay to summering areas in the Canadian arctic archipelago (Fig. 1). Some enter the archipelago via Lancaster Sound, north of Baffin Island, whereas others summer along the northeast coast of Baffin Island (Davis and Koski 1980; Reeves *et al.* 1983a). The most southeasterly of the major late summer concentration points observed during recent years is at Isabella Bay, east-central Baffin Island (Finley 1990), During the 19th century, many bowheads were killed somewhat farther to the southeast in August and especially in September (Ross and MacIver 1981).

The old whaling literature contains many suggestions that different components of the population concentrated in different summering areas. Subadults, cows and calves were said to concentrate to the north and west, off northern Baffin Island. In contrast, whales found along eastern Baffin Island were said to be primarily large animals without calves (Eschricht and Reinhardt 1866; Brown 1868; Southwell 1898; Lubbock 1937). Recent evidence provides some support for these ideas (Finley 1990; Reeves and Mitchell 199 1).

In autumn, bowheads that summer farthest north and west migrate east past northern Baffin Island and then south along the coast of eastern Baffin Island. They have been monitored from a cliff top observation site at Cape Adair (Fig. 1) during two autumn seasons (Koski and Davis 1979, 1980). During October, these whales migrate south past Isabella Bay and other concentration points along eastern Baffin Island, possibly intermingling with individuals that spend the late summer there. Baffin Bay usually is largely ice-free during this period.

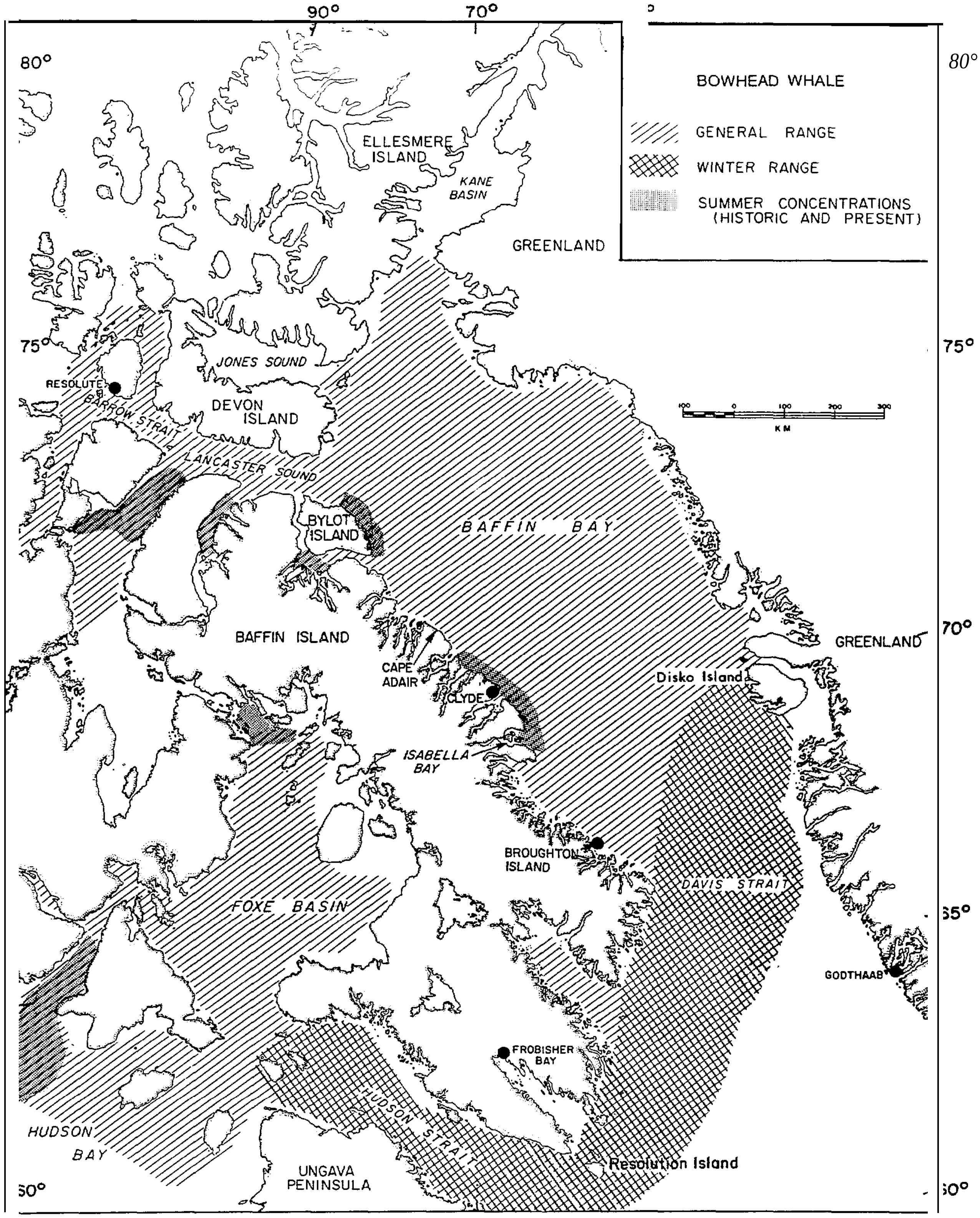


Figure 1. Distribution and important summering areas of the bowhead whale in the eastern Canadian Arctic.

There has been no offshore oil drilling in the summer or early autumn range of the Davis Strait/Baffin Bay bowheads. There has been only a very limited amount of oil exploration in the winter range off the west coast of Greenland and in Davis Strait, and little of that activity was during the winter when bowheads might be present. There has been some seismic exploration in these areas, Prior to this study, the amount of seismic exploration in the range of the Eastern Arctic bowheads had not been compiled, but it was believed to be much lower than the amount within the range of Western Arctic bowheads. There is commercial fishing in Davis Strait and subsistence fishing off the west coast of Greenland, but little of this is in winter when bowheads are present in those waters. There is limited summer shipping in various parts of the range, along with local movements of small boats around communities. As noted above, there is no hunt for bowheads in the eastern arctic.

Summarv of Rationale

It appears that, in recent decades, the Davis Strait/B affin Bay bowheads have been exposed to much less human activity than have the Bering/Beaufort bowheads. Thus, the former group might be considered a control population against which the behavior of Bering/Beaufort bowheads can be compared. This provides a possible approach for evaluating whether the increasing human activity in the range of the Bering/Beaufort stock has led to long-term changes in behavior.

Objectives

The overall objective of the present study is to determine whether there is any evidence of differences in the behavior of the Bering/Beaufort and Davis Strait stocks of bowheads that can be attributed to cumulative, long-term effects of the (assumed) greater degree of exposure of bowheads to human activities in the western arctic. This overall objective has been formulated by MMS as a test of the following null hypothesis:

> HO: There are no significant differences in normal behavior between bowhead whales of the Bering/Beaufort and Davis Strait stocks.

In order to test this hypothesis and interpret the results, it was necessary to analyze the existing but previously-unanalyzed data on the behavior of the Davis Strait bowheads, compare their behavior with that of the Bering/Beaufort stock, quantify the relative amounts of human activity to which the two stocks have been exposed in recent years, and evaluate whether any observed differences in behavior are attributable to differences in human activities.

MMS formulated the specific objectives in the following way:

1. Analyze recently collected raw data on the normal behavior of bowhead whales on their summer feeding grounds in the fiords of eastern B affin Island.

2. Relate observed behaviors to natural features including depth, turbidity', nearness to shore, time of year, weather, and ice conditions. Compare these observations with those from the Beaufort Sea feeding areas. [Observations along fall migration routes were also compared.]

' Specific data on this point were not available.

3. Quantify and describe the similarities and differences in observed normal behavior of Davis Strait bowheads vs. comparable bowheads in the Beaufort Sea.

4. Quantify the differences in degree of exposure to offshore oil and gas activities, and other human activities, between the Bering/Beaufort and Davis Strait bowhead stocks.

5. Perform appropriate statistical analyses to identify statistical significance and for hypothesis testing.

6. Search for correlations between observed behaviors and degree of exposure to human caused activities.

Approach

The study was planned as a two-phase project. In Phase 1, the behavior of the two stocks of bowheads was compared. Phase 1 encompassed objectives 1-3 and (in part) 5 from the above list (Richardson and Finley 1989). In Phase 2, the relative exposure of the two stocks to human activity was to be determined, and behavioral similarities and differences between stocks were to be evaluated in relation to differences in human activities (objectives 4, part of 5, 6). The present report presents the results from Phase 2 of the project.

Phase 1

During Phase 1, we used behavioral data collected during previous studies in the absence of known sources of potential disturbance to compare normal behavior of Davis Strait/Baffin Bay (control) vs. Bering/Beaufort bowheads. Two main approaches were used to distinguish within-stock from between-stock variation.

1. The behavior of Davis Strait bowheads was examined relative to environmental variables (e.g., water depth, sea state, ice *cover,* distance from shore, date, time of day) and whale activities (e.g., feeding, socializing, local travel, migration) to identify sources of within-population variation. Analyses of these types had already been done on many of the western arctic data--Würsig *et al.* (1984a, 1985a,b, 1986); Koski and Johnson (1987); Richardson *et al.* (1987b); Dorsey et *al.* (1989). However, results from different western arctic studies had not always been combined in optimal ways during previous studies, so additional analyses of western as well as eastern arctic data were necessary during Phase 1.

2. Appropriate subsets of the western and eastern arctic data were selected to provide the maximum possible degree of comparability. For example, behavior of Davis Strait bowheads that were feeding in the water column in deep water (a common situation at Isabella Bay) was compared with behavior of Bering/Beaufort bowheads feeding in the water column at deep locations.

After identifying comparable sets of data for the two stocks, we compared behavior in three ways:

- univariate statistical analyses of individual behavioral variables (e.g., surface times, dive times, number of blows per surfacing, etc.),
- multivariate statistical analyses of a variety of variables considered simultaneously, and
- qualitative and quantitative examination of types of activities and vocalizations exhibited by the two stocks of bowheads under comparable conditions.

Based on these analyses, we assessed the validity of the null hypothesis of no difference between the behavior of the two bowhead populations. As summarized in a later section, differences in the behavior of the eastern and western arctic populations were found. Some of these differences were attributable to differences in the natural environments of the two populations, or to differences in the age/sex composition of the whales that were studied. However, we could not fully account for some apparent regional differences in behavior, especially in the case of autumn-migrating bowheads, based on natural factors alone. These results and interpretations were all presented in the Phase 1 report (Richardson and Finley 1989), and are only summarized in this report.

Phase 2

In Phase 2, human activity information was compiled for the various areas occupied by Davis Strait and Bering/Beaufort bowheads in different seasons. We assume that the overall behavior of a population of whales might be influenced by human activities encountered at seasons other than those when the whales are observed. Therefore, we consider human activities that bowheads might encounter at any time of the year. We considered the period 1974 to 1986. This 13-year period began long enough ago to include the years of significant oil-industry activity in the western and eastern arctic. We used 1986 as the end point because that was the last year for which a substantial quantity of data on bowhead behavior was available for either the western or eastern arctic during summer or autumn.

Many of the necessary western data on human activities had already been compiled, prior to this project, during previous projects for the U.S. and Canadian governments (Richardson et *al.* 1985a, 1987a; Norton and McDonald 1986; Norton *et al.* 1987; Brouwer *et al.* 1988). Some additional work was necessary to complete the data compilation for the western arctic. Much more effort was needed to compile corresponding data for the Davis Strait/Baffin Bay area, since no related compilations of human activity data had been prepared previously for that region.

Based on these human activity data, we assess whether any of the between-stock differences in behavior demonstrated in Phase 1 can be attributed to differences in the cumulative effects of human activities. As recognized from the outset of this project, this is a difficult task. One of the major problems is the difficulty in attributing observed differences in behavior to specific causes when many factors (natural as well as human activity) vary simultaneously. Another problem is the impossibility of isolating discrete, independent units of observation for the eastern or western populations; thus, a statistical approach is impossible. The final evaluation must rest on a "weight of evidence" approach.

SUMMARY OF BEHAVIORAL COMPARISONS (PHASE 1)

During Phase 1 of the project, we compiled and analyzed existing but previously unanalyzed data on the behavior of the Davis Strait bowheads, and compared their behavior with that of the Bering/Beaufort stock.

Data Sources and Methods

The western arctic data used for these analyses came from three studies funded by BLM/MMS or the oil industry and conducted by LGL in the 1980-86 period, plus a study conducted for MMS by the Naval Ocean Systems Center (NOSC) in 1983:

1. The LGL/MMS study of behavior and disturbance responses by bowheads summering in the Canadian Beaufort Sea in 1980-84 (Richardson [cd.] 1985).

2. The LGL/MMS study of bowheads feeding in the eastern Alaskan Beaufort Sea during September of 1985 and 1986 (Richardson *et al.* 1987b).

3. The LGL/Shell Western study of bowheads migrating past drillsites in the Alaskan Beaufort Sea during the autumn of 1986 (Koski and Johnson 1987).

4. The NOSC/MMS study of bowheads near seismic vessels in the Alaskan Beaufort Sea during the autumn of 1983 (Ljungblad *et al.* 1984b). Heavy ice conditions prevented most seismic exploration in 1983.

The data that were considered were those collected when no significant source of man-made underwater noise was present. All data collected in the four western arctic studies were collected by aerial observers using a standardized observation method. The aircraft circled at an altitude of at least 1500 ft (457 m) during all observation sessions considered here. This has been shown to be high enough to avoid significant disturbance by the observation aircraft (Richardson *et al.* 1985b,c).

The eastern arctic data were collected during two LGL shore-based studies along the east coast of Baffin Island:

5. A study of bowheads migrating south past Cape Adair (Fig. l) in the autumn of 1979. Limited additional data were available from 1978 (Koski and Davis 1979, 1980).

6. A study of bowheads summering at Isabella Bay (Fig, 1) in the late summer - early autumn periods of 1984-86. Limited additional data were available from 1983 and 1987 (Finley *et al.* 1986; Finley 1987, 1990).

In both eastern arctic studies, most data came from a theodolite deployed on a coastal hill or cliff. The theodolite was about 209 m above sea level at Cape Adair and 136 m above sea level at Isabella Bay--high enough to allow observations and tracking of whales several kilometers away. Aerial surveys provided supplementary data in 1978-79. At Isabella Bay, data on zooplankton and underwater sounds were acquired occasionally from boats, and approximate whale sizes were determined in 1986 by aerial photogrammetry (Finley 1990).

LGL's western arctic data (studies 1-3) were already available in a standardized computer-readable format prior to the present study. At the start of this project, they were converted into an improved format incorporating some additional variables. LGL's eastern arctic data, which had not previously been anal yzed in detail, plus NOSC's 1983 western arctic data, were coded in the new format, entered into a computer, and validated.

Selection of Compatible Data Subsets

The first major step of the analysis was to identify comparable subsets of the eastern and western arctic data. Previous analyses of the behavior of Bering/Beaufort bowheads in summer and autumn have shown that the surfacing, respiration and diving cycles as well as other aspects of behavior are quite variable. Much of this variability is attributable to inherent variability of behavior among individual whales and within individuals over time. However, many aspects of behavior are correlated with

- the environmental circumstances (water depth, ice cover, date, etc.),
- the activities of the whales (e.g., feeding at depth vs. at surface, socializing, traveling), and
- the size and status of the whales (e.g., subadults, adults, mothers, calves).

The main studies in which these relationships have been investigated are Ljungblad *et al.* (1984b), Würsig et *al.* (1984a, 1985b, *1989)*, Richardson *et al.* (1987b, 1990a), and Dorsey et *al.* (1989). Behavior can also be affected by proximity to various human activities.

In this project, it was important to compare the normal behavior of the two stocks of bowheads under conditions when environmental circumstances, whale activities, and whale status were as similar as possible. Only by standardizing the data in this way is it possible to examine the possibility y that the overall behavior of the two stocks differs. Thus, it was necessary to select subsets of the western and eastern arctic data that were as comparable as possible.

Review of data from the two regions indicated that meaningful samples from "presumably undisturbed" whales were available for four circumstances:

Whales feeding in deep water:

- no known disturbance source nearby,
- water depth >50 m (since feeding was rare in shallower water at Isabella Bay),
- mothers and calves excluded (since neither occurred at Isabella Bay),
- group activity = feeding, travel + feeding, or socializing + feeding,
- not actively socializing during current surfacing or dive,
- predominant feeding mode = water column feeding (i.e. exclude near-surface and near-bottom feeding cases, which did not occur at Isabella Bay).

Whales socializing in shallow water:

- no known disturbance source nearby,
- water depth ≤50 m (since socializing was rare in deeper water at Isabella Bay),
- mothers and calves excluded,
- group activity = socializing, travel + socializing, or socializing + feeding.

Whales engaged in local travel (Isabella Bay only):

- no known disturbance source nearby,
- mothers and calves excluded (neither occurred at Isabella Bay),
- group activity = travel,
- exclude traveling whales seen at Isabella Bay on 5-7 Ott 1986, which were migrating.

Whales engaged in migration:

- no known disturbance source nearby,
- mothers and calves excluded,
- group activity = travel,
- dates restricted to those when all traveling whales were engaged in long-distance travel. In east, this included all Cape Adair observations plus traveling whales seen at Isabella Bay on 5-7 Ott 1986. In west, this included all traveling whales seen after 11 September.

Based on these criteria for the data subsets, Richardson and Finley (1989) summarized the behavior of the whales engaged in each activity in the Eastern Arctic and, separately, the Western Arctic.

Bowheads Feeding in Deep Water

Most feeding activity at Isabella Bay occurred in deep water over glacial-remnant troughs several kilometers offshore. Essentially all feeding was of the type recognized in the western arctic as "water column feeding" (see Würsig *et al.* 1985a for description). T-here was little evidence of coordinated feeding behavior between different individual whales. However, surfacing-dive sequences of some "paired" whales were synchronous. Near-surface feeding apparently was rare, and near-bottom feeding was not detected. Whales feeding in a trough >200 m deep several kilometers northeast of the observation site on Cape Raper moved back and forth through the area from one surfacing to the next. When at the surface, bowheads often defecated, and fecal samples (n = 2) contained remnants of large copepods. Limited zooplankton sampling indicated that concentrations of large copepods occurred at depths >100 m.

Bowheads feeding in deep water off Isabella Bay exhibited long dives and surfacings, with many respirations per surfacing. An average surfacing-respiration-dive cycle consisted of a 15.8 min dive followed by a 4.7 min surfacing during which the whale respired 17 times. This behavior is consistent with diving to great depths. The interval between successive blows within a surfacing averaged 16.9 s. Within this category of whales, surfacing-respiration-diving behavior was correlated with few of the environmental variables that we considered, Aerial activity (breaches, tail slaps, flipper slaps) was very infrequent. Most surfacings of feeding bowheads ended with a "fluke-out" dive.

Bowheads feeding in deep (>50 m) water off Isabella Bay exhibited much longer surface times and many more blows per surfacing than did those feeding in deep waters of the Beaufort Sea ($P<0.001$). Multivariate analysis indicated that these differences could not be accounted for by differences in any of the measured environmental variables or whale activities. Thus, Richardson and Finley (1989) concluded that there were real east-west difference in these attributes of behavior. The eastern whales also had longer intervals between successive blows (PcO.001) and longer dive durations ($P< 0.05$), but the proportional differences were not as large. The difference in mean blow interval was probably an actual east-west difference. The cause of the slight east-west difference in mean dive durations was uncertain.

An important unknown factor is the actual depth to which the whale dove during each surfacing-dive cycle. In gray and humpback whales, depth of dive is strongly and positively correlated with most surfacing-respiration-dive variables (Würsig *et al.* 1986; Dolphin 1987a,b). We suspect that an average feeding dive off Isabella Bay was considerable y deeper than an average feeding dive observed in the Beaufort Sea. There is indirect evidence that prey 'concentrations tend to occur at greater average depths off Isabella Bay.

Bowheads Socializing in Shallow Water

Bowheads socializing in shallow water (≤50 m) at Isabella Bay often were engaged in very active social activity, frequently with an obvious sexual component. Groups of interacting bowheads seemed to contain a considerable proportion of large subadults, whereas pairs of interacting whales often appeared to be adults. Socializing bowheads produced many underwater calls and other sounds. High proportions of their calls were of the types that have been associated with active social interactions in western arctic bowheads and southern right whales.

Socializing bowheads at Isabella Bay tended to exhibit quite short surfacing-dive cycles with few respirations per cycle. An average cycle consisted of a 1.6 min dive and a 1.2 min surfacing with 2 blows spaced 17.7 s apart. Surfacing, respiration and dive variables were not correlated with many of the environmental variables examined. Within a given observation session, the socializing bowheads at Isabella Bay seemed to concentrate on social interactions. Within periods lasting minutes or hours, they normally did not intermix socializing with feeding, contrary to the situation in summer in the western arctic. Aerial activity and active social interactions occurred during unusually high percentages of the surfacings.

The behavior of socializing bowheads at Isabella Bay differed in several respects from that of bowheads socializing in shallow waters of the Beaufort Sea. At Isabella Bay, swimming speeds tended to be lower, aerial activities were much more frequent ($P << 0.001$), and fluke-out dives less frequent ($P << 0.001$). Harmonic calls tended to be much more prolonged than those heard in the Beaufort Sea. A mechanical "CR-UNCH" sound was also heard near socializing bowheads at Isabella Bay but not in the western arctic. Surface times were shorter at Isabella Bay and the number of blows per surfacing lower, even after allowance for the effects of other variables ($P<0.001$ in each case). Mean blow intervals were lower at Isabella Bay than in the west ($P<0.001$). However, this last difference may have been attributable to regional differences in some of the corollary environmental or whale activity variables, Durations of dives did not differ significantly between regions.

The results provide clear evidence of differences in the behavior of socializing bowheads in the two study areas. However, one cannot necessarily conclude that the differences were attributable to between-population differences in socializing behavior. The socializing bowheads observed at Isabella Bay were predominant y large subadults or adults without calves, whereas those observed in shallow waters of the Beaufort were mainly smaller subadults. Presently available data on socializing whales do not allow an evaluation of the relative magnitudes of population (east-west) differences in behavior versus effects of whale size, age, or reproductive status. It is noteworthy, however, that sexual activity was common at Isabella Bay even though it has rarely been observed anywhere in the Beaufort Sea during late summer or autumn, even in places where adult and large subadult whales were common.

Bowheads Engaged in Local Travel

Local travel was a common activity of whales at Isabella Bay, mainly involving singletons or pairs of whales. Most of these whales were traveling between the main locations where feeding and socializing took place. Swimming speeds were usually slow, Durations of surfacings and dives were intermediate between the high values of feeding whales and the low values of socializing whales. The same was true of the number of blows per surfacing. That variable, along with dive duration, was not correlated with many of the environmental variables considered. Surface times and blow intervals were correlated with several other variables; however, these results seemed to be largely a result of a relationship to one dominant variable that affected several of the others. Little active socializing occurred during local travel. Flipper and tail slaps were somewhat more common, but still infrequent. Most dives began without the flukes being raised above the surface.

Local travel undoubtedly occurred commonly in the Beaufort Sea as well. However, it was not as readily recognizable there, probably because of differences between the aerial observation method used in the west versus the coastal observation method used in the east. Too few definite cases of local travel could be isolated in the western arctic to allow comparisons with the eastern arctic data.

Bowheads Engaged in Autumn Migration

Migrating bowheads travelled consistently southeastward along the coast of Baffin Island at comparatively high speed, usually as singletons or pairs. Typical travel speeds were about 5-6 km/h. These speeds were maintained over periods of at least several hours, and in one case. probably for at least 28 h. The peak of the migration past Cape Adair (250 km north of Isabella Bay) was in early October during each of the two years of observation there (1978-79). The migration corridor was within 1 ½ km of shore at Cape Adair and probably also at Isabella Bay.

In the eastern arctic, mean duration of surfacing, duration of dive, and number of blows per surfacing were intermediate between values for feeding and socializing whales, and generally similar to values during local travel. An average surfacing-dive cycle by a whale migrating along the Baffin Island coast consisted of a 9.3 min dive and a 1.5 min surfacing with 6 blows spaced an average of 17.1 s apart. However, migrating whales spent less time at the surface (14%) than any other category of whale in the eastern arctic. Durations of both surfacings and dives by migrating bowheads tended to be lower when sea state was high than when it was near-calm. Socializing and aerial activity were very uncommon during migration. Fluke-out dives were common, although less so than during feeding in deep water.

The physical situations, activities, behavior and (presumed) age composition of migrating bowheads observed in the eastern and western arctic were similar in many respects. The main difference. in circumstances was that most migrants observed in the west were many kilometers offshore over the middle-shelf region, whereas those observed in the east were ≤ 1 ½ km from shore. In both regions, group sizes were generally 1 or 2, and there was very little socializing or aerial behavior. Fluke-out dives seemed to be more common in the east.

Dive durations averaged longer in the west than in the east ($P<0.01$), whereas surface times were similar in the two regions. As a result, bowheads were at the surface for a lower percentage of the time in the west (1 O% vs. 14%). In both areas, bowheads were at the surface for a smaller proportion of time during migration than during the other activities that were studied. The number of blows per surfacing and the mean blow interval were similar in the east and west.

Overall, the behavior of migrating bowheads in the eastern and western arctic was more similar than was the case for either feeding or socializing bowheads. However, there was a significant difference in dive durations. The frequency of fluke-out dives apparently also differed.

Reactions to Human Activities in Eastern and Western Arctic

The primary objective of Phase 1 of this study was to determine whether there are differences in the “normal” behavior of eastern and western arctic bowheads. Thus, all analyses summarized above were based on observations of bowheads that were *not* exposed to any obvious source of potential man-made disturbance at the time of the observations. A variety of regional differences in behavior were identified. The purpose of Phase 2 of the project, described in later sections of this report, is to determine whether some of these differences can be ascribed to long-term, cumulative effects of the higher level of human activities in the western arctic.

In interpreting the possible long-term effects of disturbance in the eastern and western arctic, it would be helpful to know whether there is any evidence that bowheads of the two populations exhibit differences in their short-term responses to human activities. Limited data are available on reactions of eastern as well as western arctic bowheads to small boats, ships, and aircraft.

Bowheads reacted strongly to boats in both the eastern and western arctic. In both regions, bowheads swam rapidly away when boats approached at high speed, sometimes when the distance was as great as 4 km (Richardson and Finley 1989). In both regions, reactions to slow-moving boats were less dramatic but avoidance was still evident. In both areas, there was evidence that bowheads often resume their normal activities soon after fleeing from an approaching boat--within ½-1 h on at least some occasions. More detailed comparisons of reactions to boats in the two regions are not possible because the data are limited and because the observation procedures and types of boats were different. However, available information suggests that sensitivity to small vessels is similar in the two regions,

Western arctic bowheads usually react strongly to direct approaches by ships, typically at distances of several kilometers. Under special circumstances, exemplified by a case of two ships approaching a cow-calf pair from opposite directions (LGL and Greeneridge 1987), reactions may occur at greater distances. It is uncertain whether any of the whales observed at Isabella Bay were disturbed by distant ships; if so, the disturbance was mild and infrequent.

During some low-level overflights by aircraft (e.g., 150 m above sea level), bowheads dive hastily in both the eastern and western arctic. During other such overflights, the whales remain at the surface and seem unaffected. In both regions, there is subjective evidence that the animals are less sensitive to aircraft when actively engaged in social interactions. Although comparative data are limited, especially for the eastern arctic, sensitivity to aircraft seems generally similar in the two regions.

As a first approximation, short-term behavioral reactions of bowheads to small boats, ships and aircraft seem similar in the eastern and western arctic. However, the available data on disturbance reactions, especially in the eastern arctic, are too meagre for detailed comparisons.

Conclusions from Phase 1

The conclusions from Phase 1 of this study (Richardson and Finley 1989) were as follows:

1. The general behavioral repertoires of the eastern arctic (Davis Strait/Baffin Bay) and western arctic (Bering/Be aufort) populations of bowhead whales are qualitatively similar. Almost all behaviors observed during late summer and autumn in the eastern arctic (along the east coast of Baffin Island) have also been seen in the west. Likewise, most of the behaviors seen during the more extensive western studies have also been seen in the east.

2. Notwithstanding conclusion (1), there were many quantitative differences between the behaviors observed in the eastern and western arctic. This was true even though east-west comparisons were restricted to whales engaged in similar activities, i.e.

   - feeding in the water column in deep water,
     socializing in shallow water, and
   - migrating in autumn.

   There were statistically significant regional differences in the behavior of bowheads engaged in all three of these activities (Table 1).

Table 1. Summary of the observed behavior of bowhead whales in the Baffin Bay (eastern arctic) area relative to that in the Beaufort Sea (western arctic). See Tables 3, 4, 11 in Richardson and Finley (1989) for details. Boldface type highlights the main E-W differences.

	While Feeding in Deep (>50 m) Water	White Socializing *in Shallow* (≤50 m) Water	While Migrating in Autumn
Distance from Shore	Closer in E	Closer in E	Much closer in E
Group Size	Similar, but pairs more common in E	**>1** more **often in** E **than** in W	**Slightly** smaller in E
No. bhd within 1 *km*	Fewer in E	Fewer in E	Fewer in E
Interspersed Activities	None In E; **travel** or **social** in W	None in E; **feeding in** W	None in either area
Predominant Feeding Mode	Water-column in E, mainly **wat.-col.** in W	None in E; **wat.-** column most common in W	
Speed of Motion	Zero to moderate in both areas	Zero to moderate; more often zero or low in E	Moderate to fast in both areas
Social Activity	Little in either area	**Much** more active in E	Rare in either area
Aerial Activity	Rare in both areas	More common in E **(P<0.001)**	Rare in both areas
Flukes Out at End of Surfacing	Common in both areas; low n in West	Less common In E **(P<0.001)**	More common in E **(P<0.001)**
Mean Blow Interval	Slightly longer in E **(P<0.001)**	Much longer in E **(P<0.001)**	Similar
No. Blows per Surfacing	Much larger **in** E **(P<0.001)**	Much smaller in E **(P<0.001)**	Similar
Duration of Surfacing	Much longer in E **(P<0.001)**	Shorter in E **(P<0.001)**	Similar
Duration of Dive	Longer in E **(P<0.001)**	Similar; short in both areas	Shorter in E **(P<0.01)**
% of Time at Surface	Higher in E	Higher in E	Higher in E

3. Environmental conditions in the Beaufort Sea and along the east coast of Baffin Island are very different. Some of the east-west differences in behavior appeared to be attributable to differences in the environmental conditions under which bowheads occurred. Other differences seemed to be attributable to differences in the activities in which the whales were engaged at the time of observation, e.g., "pure" socializing in one area at Isabella Bay, Baffin Island, vs. intermixed socializing plus feeding in the Beaufort. However, even after allowance (insofar as possible) for the effects of these corollary variables on behavior, several aspects of behavior remained highly significantly different between the whales observed in the eastern and western arctic.

4. The surfacing-dive cycles of whales feeding in deep (>50 m) water were much more protracted in the eastern arctic than in the west, with many more respirations per surfacing (Table 1). These differences were evident even after allowance for regional differences in measured environmental variables. However, one potentially relevant corollary variable that could not be measured was depth of dives. It is suspected that the behavioral differences were at least partially attributable to a greater average feeding depth in the east. In the absence of specific data on depths of dives, it is uncertain whether the observed strong east-west differences in behavior among feeding whales were attributable to differences in depths of dives or to some other regional difference,

5. Behavior of bowheads socializing in shallow (≤50 m) water differed strongly in many respects between the Beaufort Sea and the Isabella Bay area of the eastern arctic (Table 1). Socializing was much more active at Isabella Bay, and obvious sexual interactions were much more common during late summer there than in the Beaufort Sea. The differences were very likely attributable in part to differences in the predominant sizes and age categories of the whales whose behavior was compared. Most bowheads socializing in shallow waters of the Beaufort Sea were small subadults, whereas most of those in shallow water at Isabella Bay were adults and large subadults. However, sexual interactions have very rarely been seen during late summer or autumn anywhere in the Beaufort Sea, including areas where there were many adults and large subadults. Given the high frequency of such behavior at Isabella Bay, there may be real differences in reproductive activities between the two stocks.

6. Bowheads engaged in autumn migration in the eastern and western arctic were the most directly comparable of the three categories of whales considered. Behavior of migrants in the two regions was generally similar. However, dive durations were considerably greater in the west, and fluke-out dives were more common in the east. Given that most of the behavioral variables examined did not differ significantly between migrants in the two regions, it is difficult to evaluate the biological significance of the two statistically significant differences that were detected.

7. Overall, it is apparent that the behavior of eastern arctic bowheads along the coast of B affin Island in late summer differs quantitative y in a number of ways from that observed in the Beaufort Sea. Some of these differences can be ascribed to differences in environmental conditions or the types of whales and whale activities that were observed in the two regions. However, other east-west differences in behavior cannot be accounted for in this way. The apparent regional difference in the frequency of sexual interactions in late summer is potentially of particular significance.

SEASONAL DISTRIBUTION OF BOWHEAD WHALES

It is necessary to understand the seasonal distribution and movement patterns of Davis Strait and Bering/Beaufort Sea bowheads in order to define the areas for which human activity data are required.

Data Sources

The literature concerning the seasonal distribution of the Davis Strait Stock (DSS) was reviewed, beginning with historical writing: and reviews of the 19th and early 20th century whaling period (Eschricht and Reinhardt 1866; Brown 1868; Southwell 1898; Low 1906; Lubbock 1937; Ross and MacIver 1981; Reeves *et al.* 1983a). Based on these documents and more recent reports, primarily of the results of aerial surveys conducted as part of studies funded by the oil industry (Finley 1976, 1987; Greendale and Brousseau-Greendale 1976; Johnson *et al.* 1976; Koski and Davis 1979, 1980; Davis and Koski 1980; Koski 1980a,b; McLaren and Davis 1982, 1983; Born and Heide-Jørgensen 1983), we integrated and summarized the available information on the seasonal distribution of DSS bowheads.

The distribution of the Western Arctic or Bering/Beaufort Stock (BBS) was determined from a review of historical whaling records (Fraker and Bockstoce 1980) and reports and reviews of studies of BBS distribution in winter (Braham *et al.* 1980a,b; Brueggeman 1982; Leatherwood *et al. 1983;* Brueggeman *et al.* 1983, 1987; Ljungblad 1986), spring and autumn migration (Braham et *al.* 1980a, 1984; Johnson *et al.* 1981; Marko and Fraker 1981; Ljungblad *et al.* 1983, 1984a, 1987, 1988), and summer (Renaud and Davis 1981; Davis *et al.* 1982, 1983, 1986a,b; Harwood and Ford 198 3; Harwood and Borstad 1985; McLaren and Davis 1985; Duval 1986; Evans and Holdsworth 1986; Ford *et al.* 1987; Richardson *et al.* 1987a).

The seasonal distribution patterns of the bowheads in each stock have been somewhat arbitrarily divided into five periods: winter, spring, early summer, late summer and autumn. These divisions are necessary to simplify later comparisons with the human activities that occur in these periods. The periods are largely based on annual cycles of sea ice conditions, which determine bowhead distribution and the types of human activities that are possible. The precise distribution of bowheads and the timing of their movements can vary from year to year in response to variable ice and oceanographic conditions.

Davis Strait Stock

Winter (January-March)

The remnant Davis Strait population winters in its historical wintering range in the pack ice near the ice edge in Davis Strait (Fig. 1; Brown 1868; McLaren and Davis 1982, 1983; Born and Heide-Jørgensen 1983) and perhaps in Hudson Strait. The winter range of the DSS is somewhat uncertain because of the unknown degree of segregation of those whales from the Hudson Bay whales, and because of a paucity of distribution information from the January to March period. The relatively large number of bowheads (26) recorded during late March of 1981 in western Hudson Strait during extremely poor survey conditions (McLaren and Davis 1982) suggests that, at least during some years, part of the Davis Strait bowhead population winters in western Hudson Strait. During the same period in 1981 only five bowheads were recorded south of Disko Island on the east side of Baffin Bay-Davis Strait despite more intensive aerial survey coverage in that area than in Hudson Strait. Similar coverage of Baffin Bay-Davis Strait on 10-24 March 1982 by McLaren and Davis (1983) recorded only seven bowheads. Thus, although some bowheads winter among the pack-ice in Davis Strait, a part of the Baffin Bay/Davis Strait population may winter elsewhere (e.g., Hudson Strait).

Spring (April-mid June)

During spring the whalers found bowheads at the 'south-west fishery' along the ice edge in Davis Strait--particularly east of Resolution Island, but also including areas to the NE and SW (Fig. 1). Whales were there as early as the first of April and as late as the end of June (Eschricht and Reinhardt 1866; Southwell 1898; Lubbock 1937; Reeves et al. 1983a). By early May the whales had begun to move northward. Winter records from this area indicate that some whales were present in the 'south-west fishery' all winter (Lubbock 1937). Brown in Southwell (1898) believed that bowheads 'pass the winter and produce their young all along the broken water off the coast of the southern portion of that [Davis] strait, also in Hudson Strait and Labrador'.

Some whales migrate north in spring near the Greenland coast, where ice conditions are lighter than in the middle and western parts of Baffin Bay. Bowheads found off Holsteinsborg (67°N) along west Greenland by shore-based whalers had moved north by early April (Southwell 1898). Recent sightings south and west of Disko Island in mid April to early May were of large whales swimming northward (Born and Heide-Jørgensen 1983). Northward movements appear to have been leisurely and extended as far north as 72-73°N. Brown (1868) believed that the bowheads that migrated along the west coast of Greenland crossed westward through the pack ice at about 71030 'N latitude during June, but the latitude of the crossing probably depended on the extent of the offshore pack ice, Recent aerial surveys indicate that bowheads begin to arrive among the pack ice east of Bylot Island as early as mid May, but only small numbers were seen there before mid June of 1978 and 1979 (Koski and Davis 1979; Koski 1980a). Other bowheads apparently moved northwest through the pack ice from more southerly latitudes later in the season when the pack ice was deteriorating and receding southward (Southwell 1898; Fig. 2). The limited available aerial survey coverage and the whaling literature suggest that few bowheads occur in extreme northern Baffin Bay during spring (Barren 1970 *in* Reeves et *al. 1983a;* Koski and Davis 1979; Koski 1980a), although there are some 19th century records there in July (Ross and MacIver 1981).

Early Summer (mid June-July)

Recent aerial surveys indicate that peak movements of bowheads through pack ice areas east of Bylot Island do not occur until mid-to-late June (Koski and Davis 1979; Koski 1980 b). The whales remain among the offshore pack ice until after the landfast ice in Lancaster Sound, Navy Board Inlet and Pond Inlet breaks up. About mid July some of the whales enter Lancaster Sound, primarily along the south side. From here they continue to late-summering areas in various channels, bays and fiords in the Canadian arctic islands, primarily around northern Baffin Island (Southwell 1898; Mansfield 1971; Finley 1976; Greendale and Brousseau-Greendale 1976; Johnson et *al.* 1976; Koski and Davis 1979, 1980; Davis and Koski 1980; Koski 1980b; Ross and MacIver 198 1; Reeves *et al.* 1983a). Other bowheads remain in the offshore pack ice in Baffin Bay until August.

Late Summer (August-mid September)

The whales that remain in the pack ice in Baffin Bay until August move into coastal concentration areas in late summer at Isabella Bay and adjacent areas along east-central Baffin Island (Fig. 1; Koski and Davis 1980; Reeves *et al.* 1983a; Finley *et al.* 1986; Finley 1990). During the 19th century, many bowheads were killed in this and adjacent coastal areas in August and especially in September (Ross and MacIver 1981; Reeves et *al.* 1983a). Although the whalers were under the impression that the whales that they killed along E Baffin Island were migrating

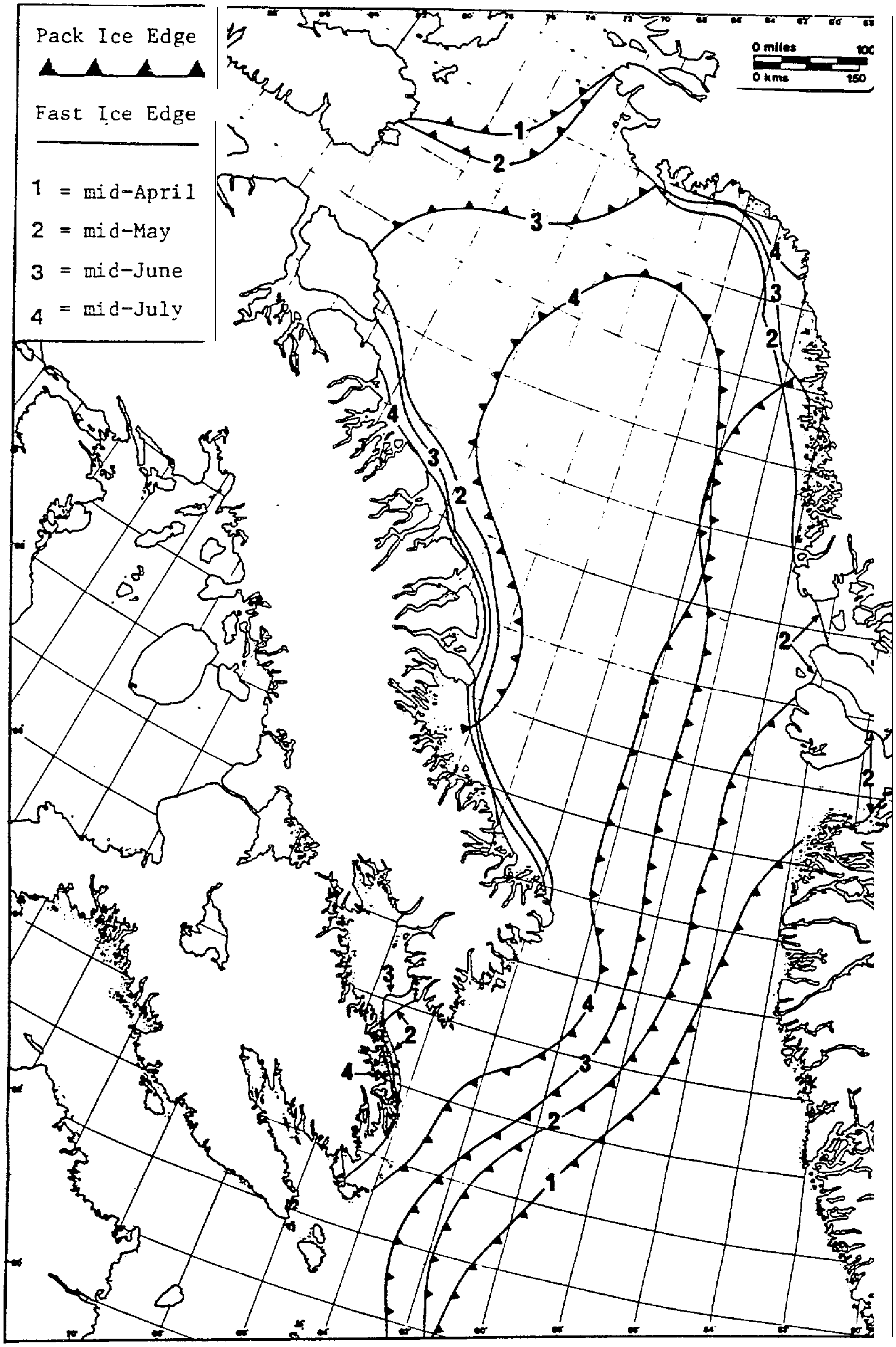


Figure 2. Average positions of fast ice and pack ice by month during spring. (From Ross and MacIver 1981, based on U.S. Navy data for 1952-1971.)

south from the Lancaster Sound-By lot Island area, recent studies suggest that this was unlikely because southward migration does not begin until late September or early October in these areas (Koski and Davis 1979, 1980; Finley 1987, 1990).

The whales that enter Lancaster Sound disperse into summering areas primarily in Eclipse Sound, Admiralty Inlet and Prince Regent Inlet. There is no indication, from the distribution noted by the whalers or from recent studies, that bowheads are normally found in channels to the west of Barrow Strait, This makes interchange between the DSS and Bering/Beaufort stock highly unlikely.

The historical whaling literature contains many suggestions that components of the population concentrated in different summering areas. Subadults, cows and calves were said to migrate into the high arctic archipelago. In contrast, whales found in late summer in fiords along eastern Baffin Island were said to be primarily large animals without calves (Eschricht and Reinhardt 1866; Brown 1868; Southwell 1898; Lubbock 1937; Reeves and Mitchell 1991). A recent photogrammetric study confirmed that whales along eastern Baffin Island are primarily large animals (Finley 1987, 1990). Eighty-nine percent of whales measured during his study were adults (i.e. >13 m) and only 1 of 107 (0.9%) individuals was a calf.

Autumn (mid September-December)

The bowheads that summer farthest north and west (i.e. primarily young animals and adults with calves, but also some other adults) migrate east past northern Baffin Island and then southeast along the coast of eastern Baffin Island. They have been monitored from a clifftop observation site at Cape Adair (Fig. 1) during two autumn seasons (Koski and Davis 1979, 1980). During October, these whales migrate south past Isabella Bay and other concentration points along eastern Baffin Island, possibly intermingling with individuals that have spent the late summer there. By October some bowheads have reached Cumberland Sound. The whaling literature suggests that bowheads remained numerous in that area until early November and, except for occasional overwintering whales, had left Cumberland Sound by early December (Low 1906; see Reeves *et al.* 1983a).

Bering/Beaufort Stock

Winter (January-March)

The Bering/Beaufort stock winters in the ice-covered waters of the northern and west-central Bering Sea. In average ice years, bowheads occur from January to March in the pack ice from St. Lawrence Island south to St. Matthew Island and west to the U.S.S.R. (Fig. 3). In years with extremely heavy ice they can occur as far south as the Pribilof Islands (Braham *et al*, 1980a). Leatherwood *et al.* (1983) found wintering bowheads to be most abundant near St. Matthew Island. Ljungblad (1986) concluded that they seem to prefer the marginal ice zone during winter, regardless of where this zone is located.

Brueggeman *et al. (1987)* studied the association between winter (January-April) bowhead sightings and pack ice conditions. Their study was based on sightings of 133 groups of 239 bowheads during more than 23,000 km of surveys flown in 1979 (Brueggeman 1982), 1983 (Brueggeman *et al.* 1983), and 1986 (Ljungblad 1986), Their analysis showed that bowheads were widely and patchily distributed in the Bering Sea. Bowheads were recorded in the marginal ice front in all three years and relatively large numbers occurred near St. Matthew Island. Although bowheads appeared to move south with the advance of the pack ice in the area between St,

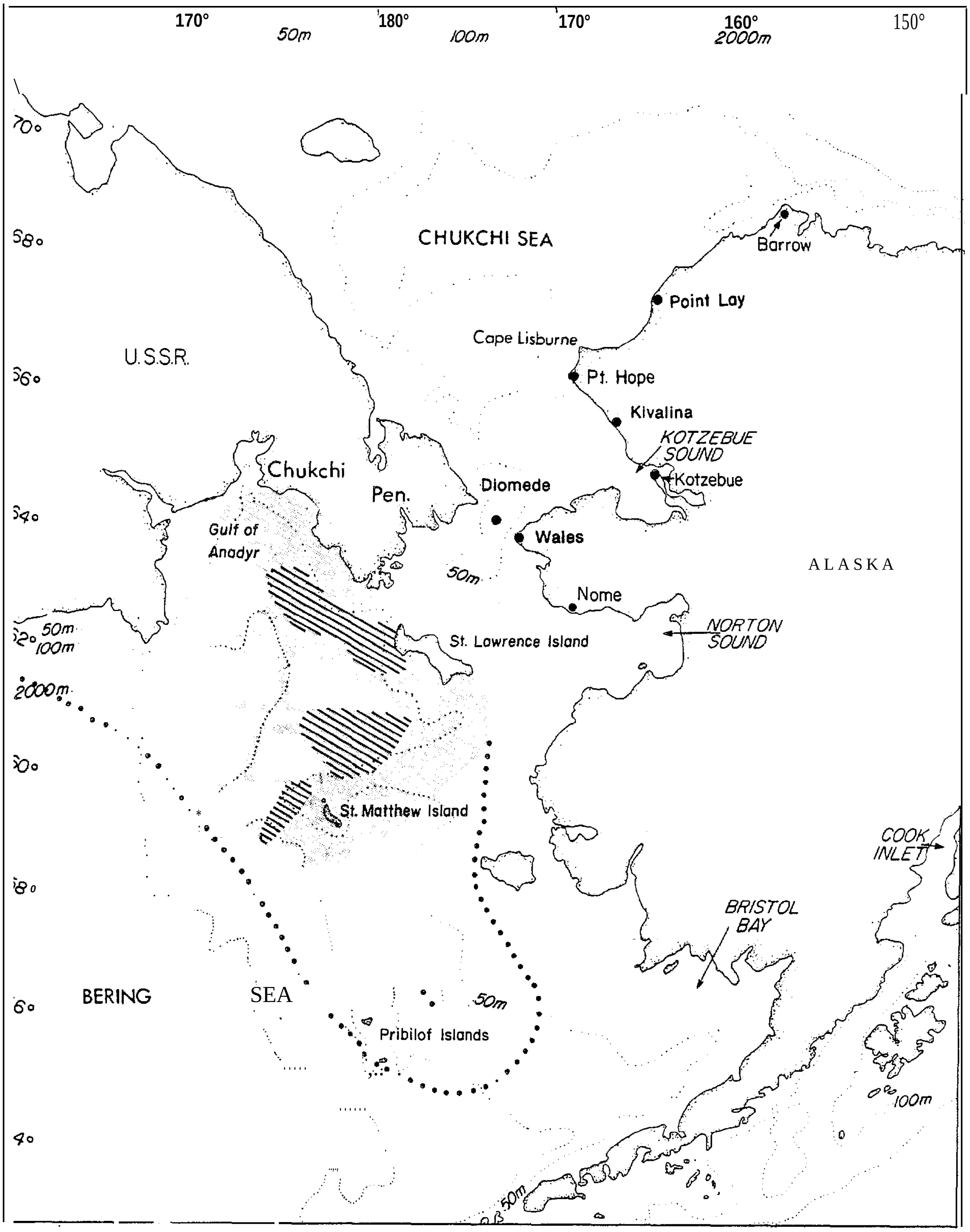


Figure 3. Winter (January-March) distribution of the Bering/B eaufort bowhead stock. Grey tone shows main wintering area. Hatched areas show concentration areas identified by Brueggeman *et al.* (1987), see text, Heavy dotted line shows extreme winter range limits that might occur in a year with abnormally heavy ice.

Lawrence and St, Matthew Islands, they remained near the recurring polynya at St. Matthew Island even when the ice front advanced well beyond the Island. Bowheads were also found south and west of St. Lawrence Island near the recurring polynyas of St. Lawrence Island and the northern Gulf of Anadyr.

Bowheads seen in the pack ice were associated with a wide variety of ice conditions but were typically in areas near persistent open water, Brueggeman *et al.* (1987) concluded that polynyas near St. Matthew Island and St. Lawrence Island and in the northern Gulf of Anadyr are important bowhead wintering areas. In addition the pack ice between 1710 and 175°W from St. Lawrence Island south to St. Matthew Island may be an important migration corridor. The areas east of St. Lawrence Island and St. Matthew Island apparently receive much lower use by bowheads throughout the winter because the pack ice is generally heavy and very compacted.

Spring (April-mid June)

The spring migration of the bowhead through the Bering and Chukchi Seas has been described in detail by Braham *et al.* (1980a, 1984), The migration begins in the western part of the northern Bering Sea when the pack ice begins to shift and break up, usually in early April. Bowheads migrate from their wintering areas in the northern Bering Sea through the Strait of Anadyr between St. Lawrence Island and the Chukchi Peninsula, taking at least two routes, Some of the whales pass close to the village of Gambell on the west end of St. Lawrence Island while others pass farther offshore. From the Strait of Anadyr they travel NNE through Bering Strait, primarily on the Soviet side (Bessonov *et al.* 1990), although hunters at Wales take bowheads along the Alaskan coast near Bering Strait in some years (Fig. 4).

Upon entering the Chukchi Sea most bowheads take a northeasterly course across outer Kotzebue Sound in leads occurring in the flaw zone. A few whales enter a polynya that typically forms between Kivalina and Pt. Hope, but most travel an offshore route past Pt. Hope and then follow a northeasterly route to Cape Lisburne. (It is possible, but unlikely, that bowheads migrate into the western Chukchi Sea in spring, since the pack ice there is very heavy with few leads. Also the Siberian Eskimos living on the north side of the Chukchi Peninsula have no history of hunting bowheads in spring, in contrast to their counterparts on the east side of the Peninsula.) The migration past Cape Lisburne follows a number of leads and occurs up to 15 km offshore. Bowheads traveling between Pt. Lay and Barrow follow nearshore leads. The timing of the migration is such that the peak migration past Barrow is usually in early to mid-May and the migration past there is essentially over by early June. However, in 1980 the migration past Barrow was delayed by about a month. This delay was attributed to an ice blockage in the Bering Strait region (Johnson *et al.* 1981).

East of Pt. Barrow the migration path taken by bowheads has been described as due east (Marko and Fraker 1981) and northeast (Braham *et al.* 1984). Aerial survey data show that near Pt. Barrow most bowheads travel in a fairly narrow corridor, Generally the corridor widens as the whales travel east. Ljungblad *et* al. (1984a) found the eastward migration corridor to be about 25 km wide at Pt. Barrow, broadening to 50 km about 120 km to the east. Marko and Fraker (1981) examined spring bowhead sightings for the years 1974-1979 and found that sightings in the Alaskan Beaufort Sea were all north of a line extending due east from Barrow.

Some bowheads arrive in the eastern (Canadian) Beaufort Sea by early May. Bowheads have been sighted in leads west, southwest, and south of Banks Island in early to mid May in a number of years (Braham *et al.* 1980a). Figure 4 shows the spring distribution of the western Arctic

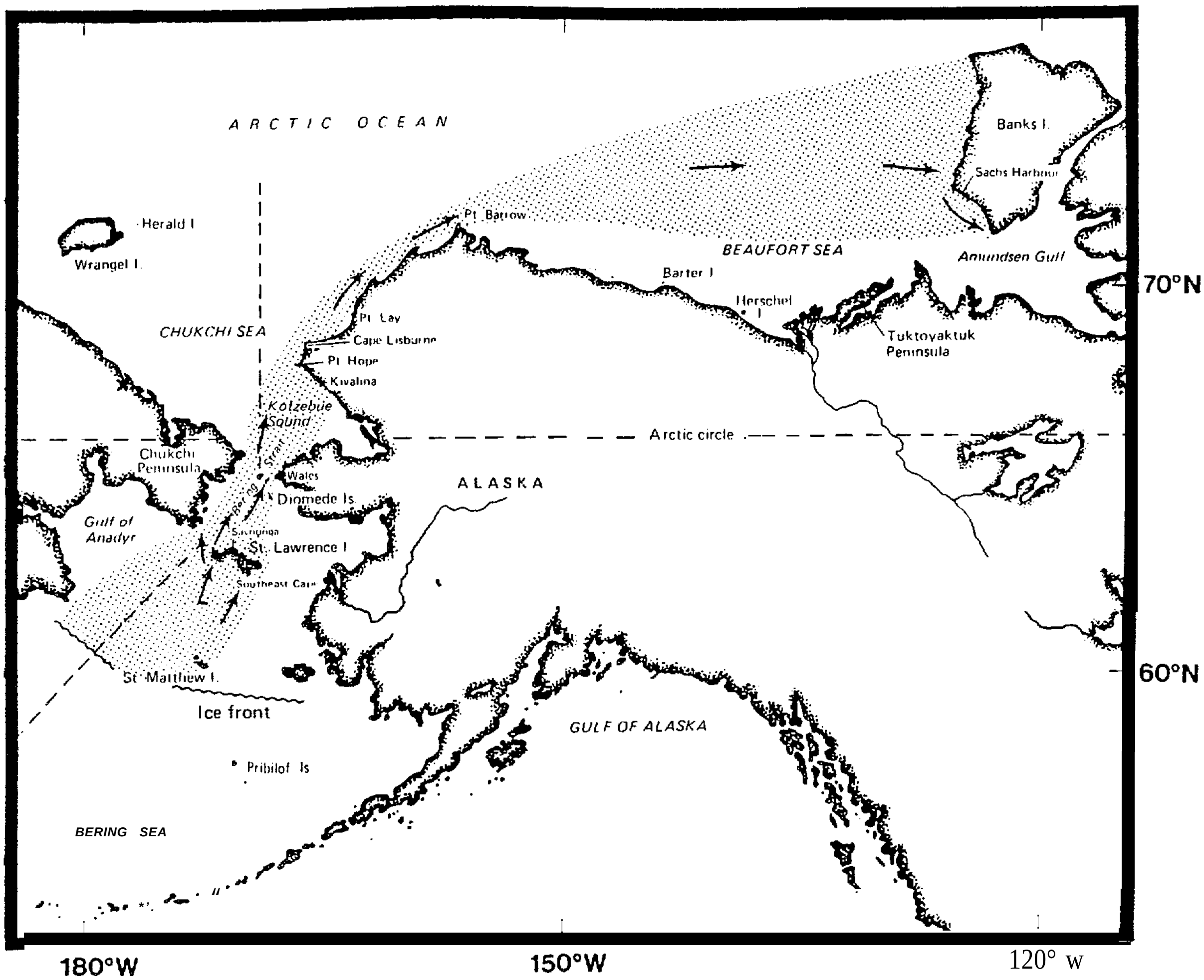


Figure **4.** Spring distribution of the **Bering/Beaufort** bowhead stock, showing generalized spring migration route, (From **Braham *et*** al. 1980a.)

bowhead stock, During this season bowheads may be distributed from the northern Bering Sea through the Chukchi and Beaufort Seas into Amundsen Gulf.

Early Summer (mid June-July)

Knowledge of bowhead distribution during the early summer period is quite limited. Historical observations and catches of bowheads during this season, compiled from whaling ship records, were limited to the Franklin Bay and Cape Bathurst regions (see Fig. 5), despite the fact that whaling ships frequently passed through the Mackenzie Bay region of the Beaufort Sea en route to the whaling grounds (Fraker and Bockstoce 1980). A small number of large scale aerial surveys have been conducted during this season.

Davis et *al.* (1982) found that in late July 1981, most bowheads in their study area (Canadian Beaufort Sea and Amundsen Gulf, north to 72°N) were in Amundsen Gulf. Much smaller numbers were present to the west in the Canadian Beaufort Sea. Davis *et al.* (1982) suggested that a substantial portion (probably over half) of the western Arctic population was not present in their study area in late July. The whereabouts of the rest of the population was not known, but based on incidental observations, they suggested that substantial numbers may have been present north of the surveyed area,

Harwood and Borstad (1985) surveyed the southeastern Beaufort Sea in July 1984. They found small numbers of bowheads present in this area in the first half of July and higher numbers in the latter half of July, Bowheads were widely dispersed throughout their study area.

In summary, from the limited data available for the early summer period, moderate numbers of bowheads are known to be present in Amundsen Gulf and very small numbers are present in the southeastern Beaufort Sea. A survey of the Canadian Beaufort Sea and Amundsen Gulf south of 72“N in 1981 failed to account for more than half of the western Arctic population. The distribution of the remaining bowheads was not known but it seems reasonable to conclude that they were probably in ice-covered waters far from potential sources of human disturbance.

Late Summer (August-mid September)

In late summer, bowheads of the BBS tend to concentrate in the southeastern Beaufort Sea (Fig. 5). Within this area distributions vary considerably among years. In various years during the 1980-1986 period, large assemblages of bowheads have been recorded in August and early September in the Herschel Canyon area north of Herschel Island, along the Yukon Coast, in offshore Mackenzie Bay, off the Tuktoyaktuk Peninsula and off Cape Bathurst (Renaud and Davis 1981; Davis *et al.* 1982, 1983, 1986a,b; Harwood and Ford 1983; McLaren and Davis 1985; Harwood and Borstad 1985; Duval (cd.) 1986; Ford et *al.* 1987; Richardson et *al.* 1987a). To the east in the Amundsen Gulf area, bowheads are known to occupy Franklin Bay during the late summer period (Davis *et al.* 1982, 1983, 1986a,b; Cubbage *et al.* 1984; Harwood and Borstad 198 5). Extensive aerial survey coverage of Amundsen Gulf east of the Parry Peninsula during this period has been restricted to studies conducted in 1981 and 1985. Only small numbers of bowheads were recorded outside of the Franklin Bay/13 athurst Peninsula region in those years (Davis *et al. 1982,* 1986b). Few whales are found in Alaskan waters during late summer. However, the western edge of the summer feeding grounds extends into the eastern Alaskan Beaufort Sea in some years (Ljungblad *et al.* 1986; Richardson *et al.* 1987 b). Although the late summer distribution of the BBS has been the subject of numerous studies since 1980, none of these studies has been able to account for the entire population, now estimated as ≈7,500 whales.

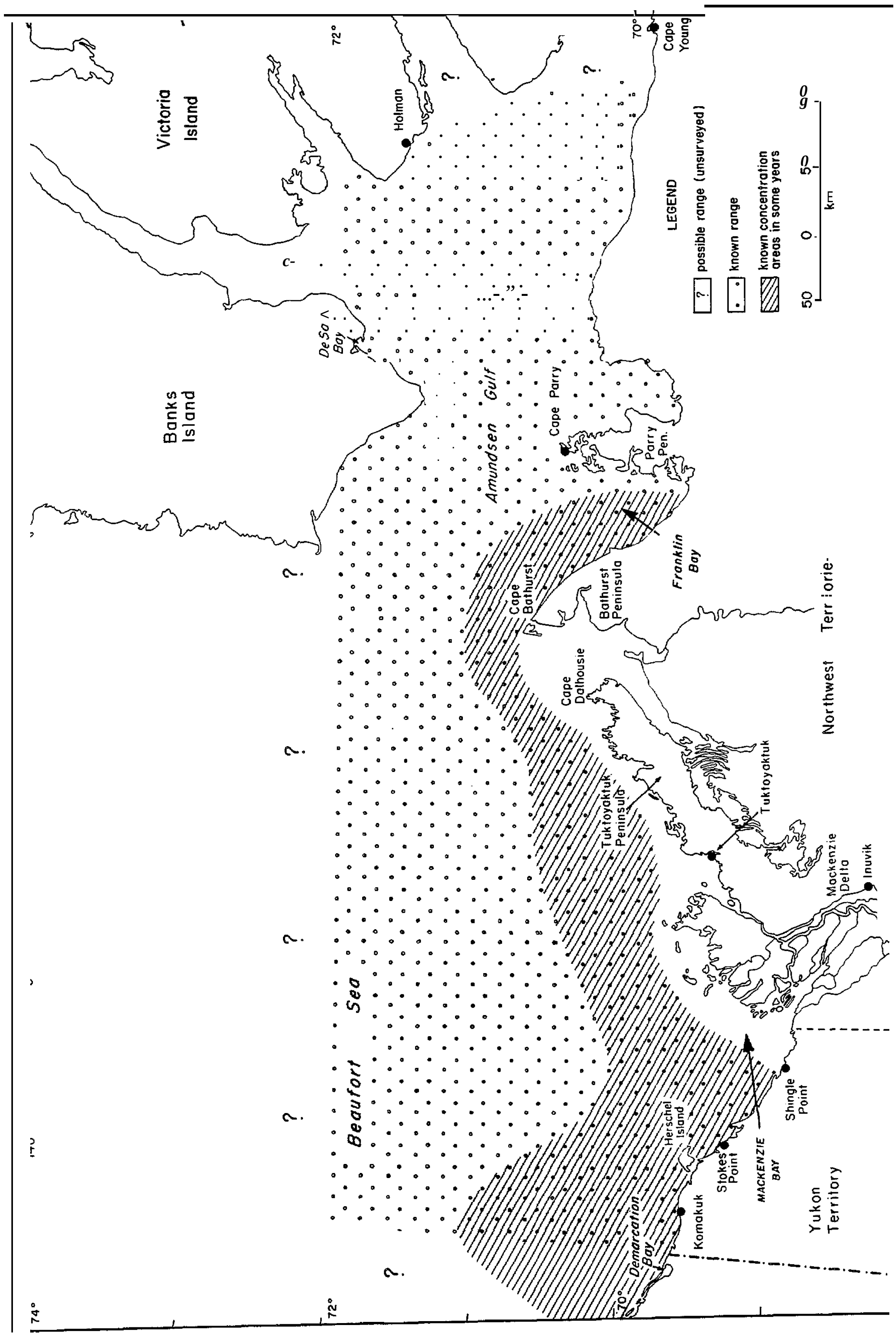


Figure 5. Late summer m m distribution of the Bering/Beaufort bowhead stock.

Photogrammetric studies have demonstrated marked geographic segregation by age category within the bowhead's known summering range (Davis *et al.* 1983, 1986a,b; Cubbage et *al.* 1984; Cubbage and Calambokidis 1987; Ford *et al.* 1987). Certain size classes of whales tend to use the same areas in different years (Koski *et al.* 1988). The whales that are found along the Yukon Coast tend to be subadults, while the whales farther offshore and farther to the east (e.g., Franklin Bay) tend to be larger whales.

During 1984 and 1985 the adult segment of the population was largely missing from the known summering range (Davis *et al.* 1986a,b). In 1982 the subadult portion of the population did not come into the Yukon Coast area and its whereabouts was not determined. In fact during most years a major portion of the adult and possibly subadult population cannot be accounted for if the current IWC estimate (7,500) is close to the actual population size. Assuming that almost all these whales enter the Beaufort Sea each year, they must be far offshore among the pack ice. Thus, in some (perhaps most) years, a substantial portion of the bowhead population may be far offshore in regions remote from human disturbance. The size, age and sex composition of this component of the population may vary from year to year.

Autumn (mid September-December)

The autumn migration of the Bering/Beaufort stock of bowheads usually starts in early or mid-September as bowheads start to leave Amundsen Gulf and the eastern Beaufort Sea en route to their wintering grounds in the Bering Sea. Migrating bowheads frequently stop to feed, so the start of migration is a subtle event, difficult to discern. In the Canadian Beaufort Sea, bowheads have remained along the Yukon Coast as late as mid-October in a number of years (Ljungblad *et al.* 1983; Evans and Holdsworth 1986). However, most bowheads pass through the western Beaufort Sea from mid-September through early October, and reach the Chukchi Sea by early-mid October (Ljungblad et *al.* 1988; Moore and Clarke 1990).

Ljungblad *et* al, (1987) described the migration route of the bowheads seen in the Chukchi Sea as a general southwest dispersion crossing roughly Herald Shoal (Fig. 6). Braham *et al*, (1984) summarized the migration west of Pt. Barrow as westerly to Herald Shoal and Herald and Wrangel Islands, then south through the Chukchi Sea.

Moore and Clarke (1991), based on aerial survey data from the years 1982-1990, suggested that the BBS may follow two routes through the Chukchi Sea. They noted an apparent bifurcation in bowhead distribution west of Pt. Barrow. They fitted one line to bowhead sightings south of 72"N latitude (n = 53) and one line to bowhead sightings north of 72"N latitude (n = 6). The line describing the southern route suggests that bowheads swim southwest from Barrow and cross the northeastern Chukchi Sea on a course that takes them near Herald Shoal. Swimming directions of these whales (n = 39) were strongly clustered about 250°T. The smaller number of whale sightings defining the northern route suggests that some whales swim across the northern Chukchi Sea on a course toward Herald and Wrangel Islands. Swimming directions of these whales (n = 6) averaged 271°T.

Large numbers of bowheads have been recorded along the north coast of the Chukchi Peninsula, USSR, in September and October (Miller et *al.* 1986; Moore and Clarke 1991) and migrating bowheads can be observed from a number of sites along the east coast of the Chukchi Peninsula in November (Bogoslovskaya et *al.* 1982). Bowheads generally enter the Bering Sea in November and December, and begin to arrive in their central Bering Sea wintering areas in December. Thus, in the mid-September through December period bowheads have a wide

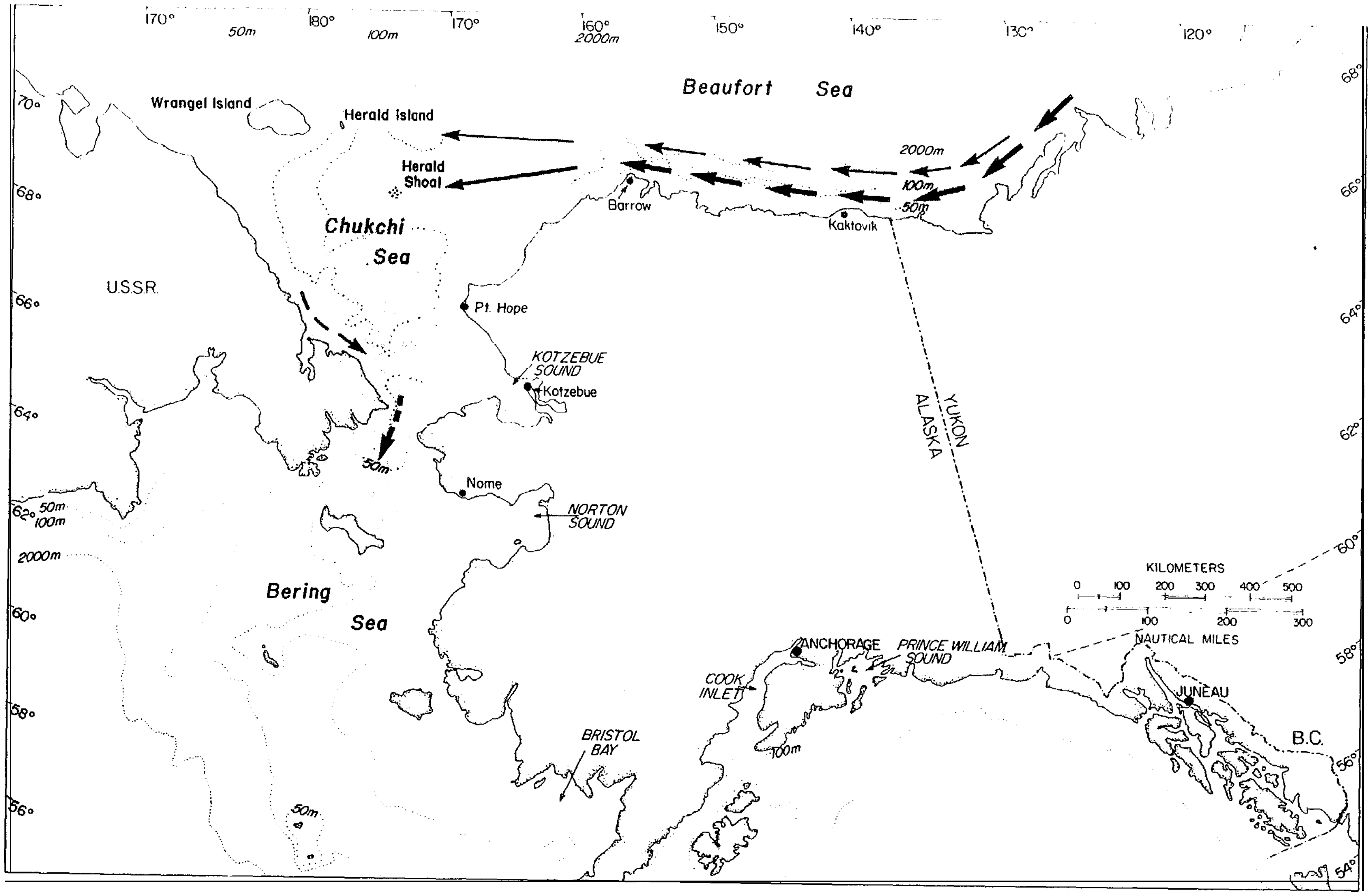


Figure 6. Autumn (mid September-December) distribution and migration routes of the Bering/Beaufort bowhead stock. Solid arrows represent observed migration route; dashed arrows indicate hypothetical routes.

distribution ranging roughly from the Canadian Beaufort Sea through the Alaskan Beaufort, Chukchi, and Bering Seas (Fig. 6).

HUMAN ACTIVITIES

Subsistence-related Vessel Traffic

The most ubiquitous sources of potential disturbance to bowheads in the North American Arctic are the small boats used by natives during hunting, fishing and nearshore travels during the open water season. Most of these boats are outboard-powered, although small numbers of larger inboards such as Peterheads are used.

Data Sources

DSS

We examined bowhead distribution in relation to the human settlements in the range of the Davis Strait stock (DSS). Settlements provide the main foci for subsistence-related boat traffic. It was not possible to assess the levels of subsistence-related vessel traffic in a direct quantitative manner (e.g., number of trips, number of km of small boat traffic). Instead we created a number of different indices of subsistence activity which, when combined, allow comparisons of relative levels of subsistence-related vessel traffic.

For villages where bowheads might be exposed to disturbance from subsistence activities we created five indices based on two different types of data. Three of these indices (human population size, number of hunters, and number of hunters who hunted) were based on population/hunter statistics to indicate potential hunting effort. The remaining two indices (estimated number of small whales harvested and estimated number of ringed seals harvested) were designed to measure hunter success. Small whales (narwhals and beluga whales) and ringed seals were chosen because boats are required to hunt these species during the open water season when bowheads are nearby. Ringed seals and belugas are hunted in both the eastern and western arctic. Narwhals are hunted only in the eastern Arctic.

Clearly, not all hunters in boats are pursuing marine mammals. For example hunters may travel by boat to desirable caribou hunting grounds, fishing rivers or outpost camps. Thus, indices of hunter success based on estimated harvests of marine mammals underestimate subsistence-related vessel traffic for communities whose hunters spend proportionately more time hunting species other than marine mammals. However, when the five indices are considered together, the combined effort/success criteria provide a reasonable indication of relative levels of subsistence-related vessel traffic. Subsistence-related vessel traffic indices were calculated for the late summer and autumn periods, when DSS bowheads are most likel y to be disturbed by subsistence activities.

Late Summer. --Subsistence activity indices were calculated from two reports of harvest levels at the five Baffin Region communities that occur in the DSS summer range--Resolute, Grise Fiord, Arctic Bay, Pond Inlet and Clyde (see Fig. 7). Population size in these five communities was reported for 1982 by Donaldson (1984). The number of hunters in a community was reported by both Finley and Miller (1980) and Donaldson (1984). Donaldson also reported the percentage of hunters in the Baffin Region study area who hunted in a given month. We applied these percentages to the number of hunters in each of the five communities to estimate the number of

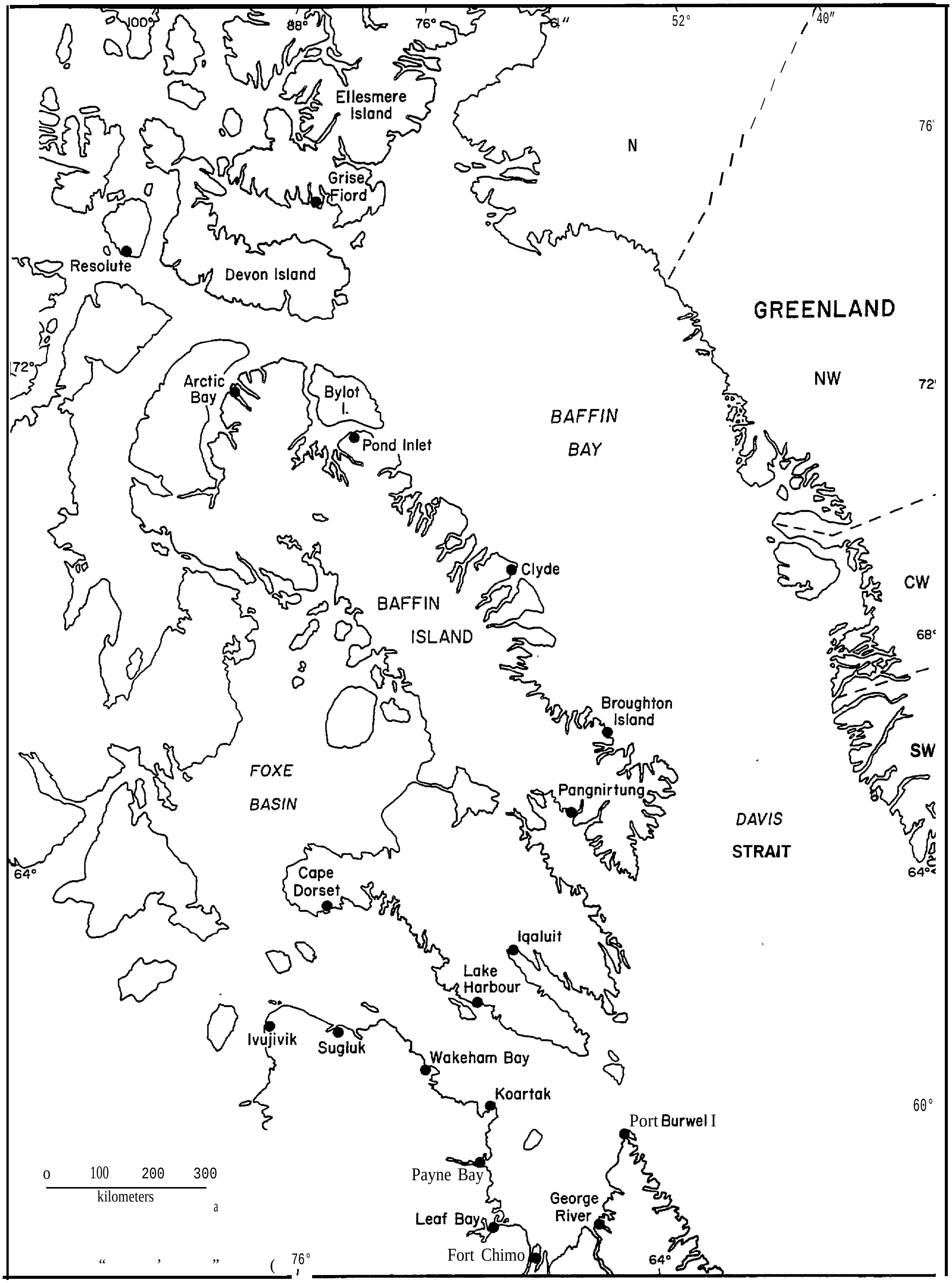


Figure 7. Locations of Canadian Arctic settlements and W Greenland districts in the DSS range.

hunters who hunted in a particular season in 1982. For example, in the late summer season the percentages of hunters who hunted were (to the nearest 5%) 75% in August and 65% in September. To calculate a percentage for the August-mid September period we divided the sum of the August percentage plus half the September percentage by 1.5. We applied the resulting percentage (71.7) to the number of hunters reported in each of the five communities.

Finley and Miller (1980) reported monthly estimated harvest levels in Grise Fiord, Pond Inlet and Clyde for the year 1979. Donaldson (1984) reported annual estimated harvest levels for 1982 in a number of Baffin Region communities including Resolute, Arctic Bay, Pond Inlet and Clyde. We applied ratios (late summer harvest : annual harvest) from the 1979 data presented by Finley and Miller (1980) to obtain a seasonal breakdown, by community, for the 1982 harvests reported by Donaldson (1984). For example, if the 1979 late summer harvest of ringed seals in Pond Inlet represented 10% of the annual 1979 estimated harvest of ringed seals there, we applied the 10% figure to Donaldson's 1982 data to estimate how many ringed seals were taken in Pond Inlet in late summer 1982. When 1979 data were not available to establish a seasonal harvest pattern for a particular community, we extrapolated using data from a nearby community.

Kapel (1975, 1977) reported mid-1970's ringed seal and small whale harvests for the villages and camps in the N Greenland (Thule) district. While not directly comparable to the 1982 data provided by Donaldson (1984) for the Baffin Region, they do provide a general indication of the levels of subsistence activities in the district. Kapel (1975) also reported the size of the human population in the Thule district.

For ringed seals we assumed that the percentage of the total harvest that was taken in the summer period in the Thule district was the same (13.1%) as that taken during the late summer season in Pond Inlet. We applied this percentage to the total annual harvest estimated by Kapel (1975).

The harvest data for narwhals and belugas presented by Kapel (1977) cover the years 1954-1975. Although these harvest data are incomplete, Kapel did specify certain years in which the harvest levels were probably typical of the entire period. We based our indices on the mean of these typical annual harvests. Kapel (1977) noted that the major catches of both these species occur in July and August. We arbitrarily assumed that half of these 'typical' harvests were taken in August, and therefore in our late summer season.

We estimated the number of hunters, and the number of hunters who hunted, in the Thule district by applying the respective percentages for Pond Inlet (in 1982) to the number of people living in the Thule district.

Finally, all five index components for the Baffin Region (1982) and Thule district were summed to arrive at the final late summer index of subsistence-related vessel traffic. It should be noted that the Thule data are not directly comparable to the Baffin data since the harvest of small whales in Thule is conducted from kayaks without motors, thereby reducing noise disturbance, Outboards are used in the Baffin region.

Autumn.--In autumn, DSS bowheads are potentially exposed to disturbance from subsistence-related vessel traffic from six Baffin Island communities (Table 2). Indices of disturbance for these communities were determined in the same manner as for the late summer period (see above). Population and harvest statistics from Arctic Bay, Pond Inlet, Clyde and Broughton Island were determined for the mid September-October period. For Pangnirtung and Iqaluit, where bowheads arrive and remain later in the season, the figures are for the October-November periods.

Table 2. Summary of the seasonal distribution of DSS bowheads and their potential for exposure to subsistence-related vessel traffic associated with eastern arctic settlements and W Greenland districts.

Village or District[1]	Season: Winter	Spring	Early Summer	Late Summer	Autumn
Resolute	-[2]			x[4]	
Grise Fiord	-		+[3]	x	-
Arctic Bay			+	x	X
Pond Inlet			+	x	x
Clyde	-	-	+	x	x
Broughton Island			·		x
Pangnirtung					x
Iqaluit				-	x
N Greenland			+	X	
NW Greenland		+	+		
CW Greenland	+	+			
SW Greenland	+	+			
Lake Harbour	+	+	·		
Cape Dorset	+	+		-	-
Ivujivik	+	+			
Sugluk	+	+		-	-
Wakeham Bay	+	+			
Koartak	+	+			
Payne Bay	+	+			
Leaf Bay	+-	+	-		
Fort Chimo	+	+	-	-	-
George River	+	+	-		
Port Burwell	+	+	-		

[1] See Figure 7 for locations.
[2] '-' = DSS not present.
[3] '+' = DSS potentially present.
[4] 'x' = DSS potentially present and exposed to subsistence-related vessel traffic.

BBS

We examined the distribution of the Bering/Beaufort Stock (BBS) in relation to the settlements within its range. For each settlement in each of the five seasons described earlier, the potential for the BBS to be exposed to disturbance from subsistence-related activities, especially vessel traffic, was assessed.

When bowheads are near the Alaskan whaling villages (spring and autumn) they are the object of subsistence whaling. This is a very different situation from that in the eastern arctic where DSS bowheads are only likely to be disturbed by subsistence activities that are directed at other species. [Kapel (1985) reported the drowning of a young bowhead in 1980 in a net set for white whales off the NW Greenland coast. However, the bowhead is a protected species in Greenland, and this incident was considered unusual.] The 'hunting effort' indices (ringed seal and small whale harvests) used for the DSS are not relevant to the BBS in spring and autumn. Ringed seal and beluga catches from boats during these seasons would be incidental to the bowhead hunt as virtually all boat-based subsistence activities are directed at bowheads. Two new indices of subsistence-related vessel traffic were calculated for the BBS: the number of whales 'struck' and the number of active whaling crews.

We used data presented by Marquette (1979); Braham *et al.* (1979, 1980b); Johnson *et al.* (1981); Marquette et *al.* (1982); Dronenberg *et al.* (1983, 1984); George and Tarpley (1986); and George *et al. (1987)* to assess the numbers of bowheads struck in spring and autumn bowhead hunts and the numbers of whaling crews participating in the hunts. Information about early and late summer beluga harvests was derived from reports by Fraker (1980); Norton and Fraker (1982); and Norton (198 3). Data concerning BBS summer ringed seal harvests and hunter statistics were obtained from the Inuvialuit Harvest Study (M. Fabijan, pers. comm.). These 1988 harvest statistics were presented by month. To extrapolate these data to the 16 June-July early summer period, one-half the June figures were added to the July figures. For the late summer period (August-1 5 September) the August figures were added to one-half the September figures. Although the 1988 statistics do not directly correspond to the 1974-1986 study period, they provide a general indication of hunter and harvest statistics in the BBS range, at least for the latter part of the study period. These figures can be considered conservative because, with the increase in oil exploration in the Canadian Beaufort in the 1980's and the development of the wage economy, hunting has declined in economic importance.

Results

DSS

DSS bowhead distribution was examined in relation to the human settlements where bowheads might be exposed to disturbance from subsistence activities, especially boat traffic (Table 2). Clearly the DSS is most exposed to disturbance from subsistence activities during late summer and autumn. During those seasons the potential for disturbance from subsistence-related vessel traffic is restricted to the vicinity of a small number of settlements. The detailed results of the seasonal assessment are presented below.

Winter. --Although DSS bowheads are distributed offshore from a large number of settlements along Hudson Strait and the West Greenland coast (Table 2), heavy ice cover and/or poor weather conditions preclude subsistence-related vessel traffic during this season. DSS bowheads have virtually no exposure to disturbance from subsistence-related activities at this time of the year.

Spring. --During this season DSS bowheads may be found offshore from a number of Hudson Strait and W Greenland communities (Table 2). However, spring subsistence activities are primarily restricted to hunting on fast ice and at fast ice edges, and are unlikely to involve the use of boats. The DSS is relatively undisturbed by subsistence activities at this time of year.

Early Summer.--In early summer, DSS bowheads gather in pack ice areas east of Bylot Island and Pond Inlet. During this season subsistence activities occur at the Pond Inlet, Navy Board Inlet and (when ice conditions permit) Lancaster Sound and Admiralty Inlet ice edges. Bowheads do occur along ice edges during this season and are probably exposed to some types of disturbance, especially noise from snowmobiles. Although hunters sometimes tow small boats to the ice edge during the early summer period, the use of these boats is very restricted and is limited to the retrieval of marine mammals shot from the floe edges. Often this use of boats does not require the deployment of outboard motors. Thus, in early summer, a few bowheads may be exposed to very limited disturbance at a small number of localized ice edges,

Late Summer. --During late summer, DSS bowheads can be exposed to disturbance from vessel traffic and other subsistence activities at five Canadian eastern arctic communities and one N Greenland district--Thule (Fig. 7, Table 2). We calculated a five-component index of subsistence-related vessel activity (Table 3). During 1982, there were 1,797 people living in the settlements of Resolute, Grise Fiord, Arctic Bay, Pond Inlet and Clyde. During the late summer period an estimated 286 of the 379 hunters hunted, and they harvested an estimated 146 small whales (11 5 narwhals and 31 white whales) and 1,295 ringed seals.

These figures are likely to underestimate harvests (and therefore subsistence-related vessel traffic) because they do not include harvests from outpost camps within the DSS's late summer range. Donaldson (1984) reported that in 1982 there were 25 outpost camps in the Baffin Region, occupied by 66 hunters. Two of the camps were near Resolute, two were near Arctic Bay and three were near Pond Inlet; these seven camps were within the DSS 's late summer range, Donaldson (1984) reported the combined estimated harvests from all Baffin Region outpost camps so it is not possible to determine precisely how much of the outpost camp harvest resulted from subsistence activities in these seven camps. If we assume that the 66 hunters were evenly divided among outpost camps then there would have been roughly 18 hunters in the seven outpost camps near Resolute, Arctic Bay and Pond Inlet. These 18 hunters would represent 4.5% of the hunters in the five Baffin Region communities listed in Table 3.

The hunters in outpost camps represented 4.4% (66 of 1,514) of the hunters in the entire Baffin Region in 1982. However their harvests, at least for some species, represented a considerably higher percentage. Outpost camps accounted for 10.1, 3.6 and 10.6%, respectively, of the total estimated Baffin Region harvests of ringed seals, narwhals and belugas in 1982, Thus, the exclusion of outpost camps from our indices has probably resulted in indices that are about 10% too low.

Bowheads are also exposed to subsistence-related vessel traffic from villages and camps in the N Greenland (Thule) district. The subsistence-related vessel traffic index calculated for this district is presented in Table 3. The population in the Thule district was 550 people, almost all of whom were hunters and their families. During the late summer period 110 of those people were hunters and an estimated 80 of them hunted. These hunters took an estimated 178 small whales (109 narwhals and 60 belugas) and an estimated 589 ringed seals. Note, however, that whale hunters in Thule use kayaks rather than outboards, thereby reducing potential disturbances to bowheads.

Autumn.--In autumn (mid September-December) DSS bowheads are potentially exposed to disturbance from subsistence-related vessel traffic from six Baffin Island communities (Table 2). In 1982 there were 5,073 people living in these six Baffin communities. Among these people were 841 hunters. An estimated 456 of these hunters hunted, and they harvested an estimated 15 small

Table 3. Indices of subsistence related vessel traffic calculated for villages with the potential to disturb DSS bowheads in late summer.'

Region	Village	Year	Village Population Size	Number of Hunters	Number of Hunters Who Hunted*	Number of Small Whales Harvested Per Year			Number of Ringed Seals Harvested Per Year
						Narwhals	Belugas	Total	
Baffin	Resolute	1982	168	38	2-1	6'	29'	35	31
"	Grise Fiord	1979		22		8	5	13	218
		1982	106	26	19	17	2	19	243
"	Arctic Bay	1982	375	95	68	34	0	34	238
"	Pond Inlet	1979		122		53	0	53	326
		1982	705	142	102	53	0	53	534
"	Clyde	1979		85		2	0	2	460
		1982	443	78	70	5	0	5	249
"	Total	1982	1,797	379	286	115	31	146	1,295
Greenland	Thule		550	110	80	109	69	178	589
Baffin and Greenland	Total		2,347	489	366	224	100	324	1,884

' Data shown for 1979 are from Finley and Miller (1980). Data shown for 1982 are from Donaldson (1984), except that the harvest data for the entire 1982 year were broken down into seasonal data using proportions (seasonal harvest: annual harvest) observed by Finley and Miller (1980) in the same or adjacent communities in 1979 (see text). Greenland data are from Kapel (1975, 1977).

' Donaldson (1984) reported percentages of hunters who hunted in a given month in her 1982 Baffin Region study. The appropriate monthly figures for the entire region were applied to each of the five Baffin Region communities shown here.

' All narwhals and belugas taken in Resolute in 1982 were assumed to have been taken during the late summer period.

whales (13 narwhals and 2 white whales) and 2,228 ringed seals (Table 4). Thus, four of the five indices of subsistence-related vessel traffic (population, number of hunters, number of hunters who hunted, and estimated ringed seal harvest) were higher in the Baffin Region during the autumn 1982 period than in the late summer 1982 period. This is primarily because the DSS distribution during the autumn season brings the whales near larger Baffin communities. However, during parts of this season (November) the only Baffin communities likely to expose the DSS to subsistence-related vessel traffic are Pangnirtung and Iqaluit. In December, except for a few individual bowheads that may overwinter in Cumberland Sound, the DSS is probably not exposed to any subsistence-related disturbance from Baffin communities. Also, much of the boating activity in autumn occurs near settlements in protected fiords. These areas are not frequented by migrating bowheads; thus the potential for disturbance is low (K.J. Finley, pers. comm.).

Eschricht and Reinhardt (1866) stated that bowheads appeared in the Upernavik District of NW Greenland in October and were sometimes present until December. There have been almost no fall records along the west Greenland coast in this century. A single immature bowhead was caught in nets set for belugas on 6 November 1980 at 73°15 ‘N in northern Upernavik District (Kapel 1985). Thus, an occasional individual may be found along the coast of NW Greenland in the autumn, but the vast majority of the population apparently occurs elsewhere. We have ignored these isolated animals off Greenland when assessing disturbance levels.

BBS

We examined the distribution of the BBS in relation to the settlements shown in Figure 8. For each settlement in each of the five seasons described earlier, we assessed the potential for the BBS to be exposed to disturbance from subsistence-related activities, especially vessel traffic (Table 5). Clearly, the BBS is potentially most exposed to disturbance from subsistence-related vessel traffic during spring, late summer and autumn.

Winter. --The BBS winters offshore in ice-covered waters far from any human settlements except the villages of Gambell and Savoonga on St. Lawrence Island and the villages of Enmelyn, Nunligran and Sireniki along the north coast of the Gulf of Anadyr (Fig, 8). The BBS is not exposed to subsistence-related vessel traffic during the winter season.

Spring.--As the BBS migrates north through the Bering and Chukchi Seas it is hunted by the residents of Alaskan villages, including Gambell and Savoonga on St, Lawrence Island, and Wales, Kivalina, Point Hope, Wainwright and Barrow along the west and northwest coasts of Alaska (Table 5). Most of the hunt is conducted from skin boats (umiaks) that are paddled quietly by the hunters. Once past Point Barrow the BBS migrates offshore, far from any villages, until some bowheads reach the vicinity of Sachs Harbour on Banks Island in early May.

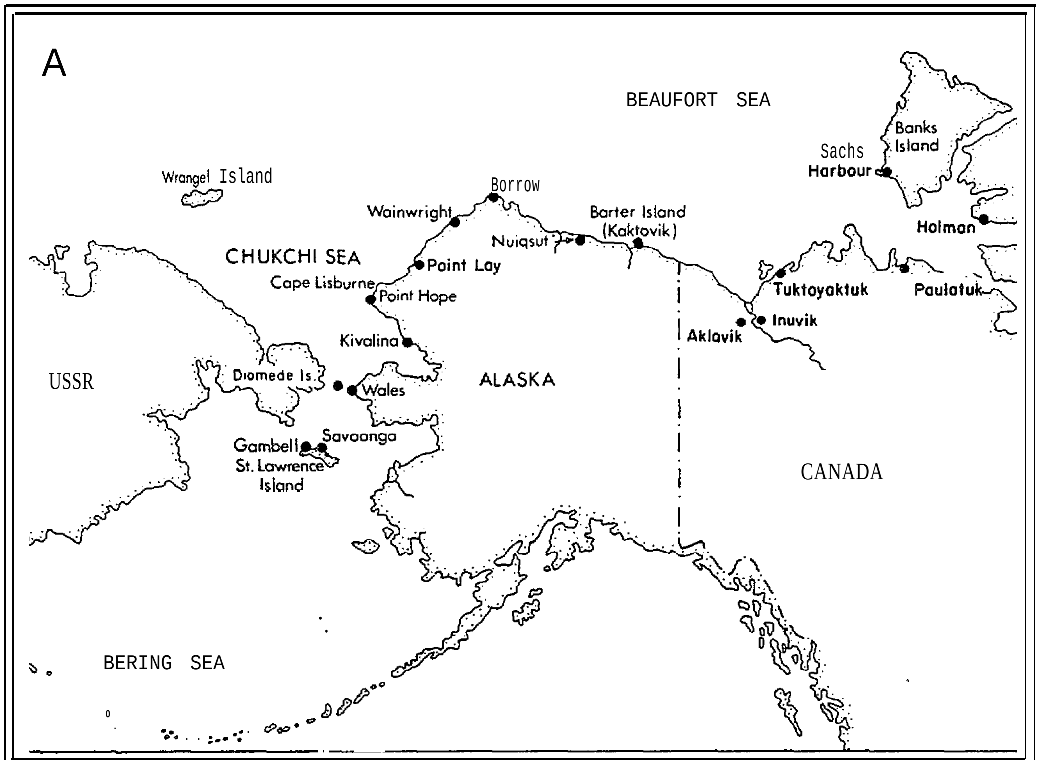
During the springs of 1974-1986, the number of whales struck by whaling crews has ranged from 15 in 1978 to 108 in 1977 and averaged 35 (n = 13, Table 6). The International Whaling Commission first imposed harvest quotas on the Alaskan bowhead hunt in 1978. Prior to that year (1974-1 977), the average number of bowheads struck was 68 per year (n = 4) compared to only 21 (n = 9) in the 1978--1986 period.

The number of whales struck during the 1974-1986 period represents a very intensive hunting effort, In the years 1974-1982 the number of whaling crews involved in the spring hunt ranged from 49 in 1974 to 99 in 1980 and averaged 84 over the nine year period (Johnson et al. 1981; Marquette *et* al. 1982; Dronenberg *et al.* 1983). Although the number of whales struck declined

Table 4. Indices of subsistence related vessel traffic calculated for Baffin Region villages within the range of DSS bowheads in autumn.

Region	Village or District	Population Size	Number of Hunters	Number of Hunters Who Hunted	Number of Small Whales Harvested Per Year			Number of Ringed Seals Harvested Per Year
					Narwhals	Belugas	Total	
Baffin	Arctic Bay'							
	1982	375	95	55	2'	0	2	197'
	Pond Inlet'							
	1979		121		3	0	3	269
	1982	705	142	83	3'	0	3	440'
	Clyde=							
	1979		86		2	0	2	520
	1982	443	98	57	5	0	5	282
	Broughton Island'							
	1982	378	92	54	34	0	3	478"
	Pangnirtung[2]							
	1982	839	166	83	0	2	2	5934
	Iqaluit[2]							
	1982	2,333	248	124	0	0	0	238'
	Total							
	1982	5,073	841	456	13	2	15	2,228

[1] Figures shown are for mid September-October period.
[2] Figures shown are for October-November period.
' Figures were derived by applying seasonal proport ions (autumn harvest: annual harvest) observed by Finley and Miller {1980) in 1979 in Pond Inlet to estimated harvests reported for 1982 by Donaldson (1984) , see text.
' Figures were derived by applying seasonal rates (autumn: entire year) observed by Finley and Miller (1980) in 1979 in Pond Inlet and Clyde to estimated harvests reported for 1982 by Donaldson (1984) .



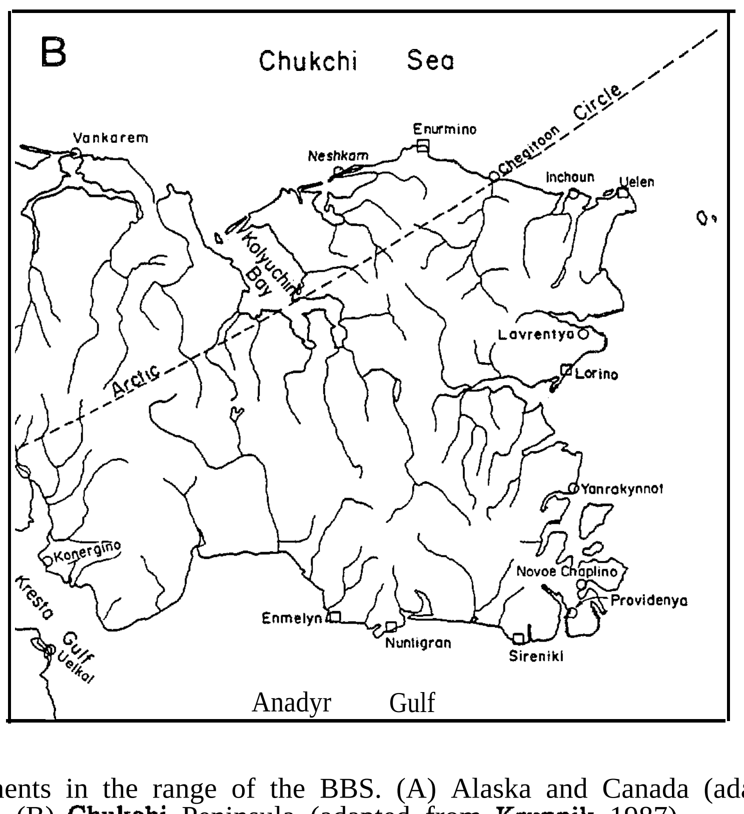


Figure 8. Settlements in the range of the BBS. (A) Alaska and Canada (adapted from Marquette 1979). (B) Chukchi Peninsula (adapted from Krupnik 1987).

Table 5. Summary of the seasonal distribution, and potential for exposure to subsistence-related vessel traffic, of the BBS bowheads with respect to western arctic settlements.

	Season				
Village	Winter	Spring	Early Summer	Late Summer	Autumn
Sachs Harbor	-[1]	+[2]	X[3]	x	
Holman			X	x	
Paulatuk		-	X	x	
Tuktoyaktuk			x	x	x
Inuvik			x	x	x
Aklavik			x	x	x
Kaktovik				x x	x x
Nuiqsut			-	x x	x x
Barrow		x x[4]			x x
Wainwright		x x			
Point Hope		x x			
Kivalina		x x			
Wales		x x			
Savoonga	+	x x			x
Gambell	+	x x			x
Enmelyn	+	+			x
Nunligran	+	+			x
Sireniki	+	+			x
Providenya		+			x
Novoe Chaplino		+	-		x
Yanrakynnot		+			x
Lorino		+			x
Lavrentya		+			x
Uelen		+			x
Inchoun		+			x
Chegitoon					x
Enurmino					x
Neshkam					x
Vankarem					x

[1] '-' = BBS not present.
[2] '+' = BBS stock potentially present,
[3] 'X' = BBS potentially present and exposed to subsistence-related vessel traffic.
[4] 'x x' = BBS present and the focus of subsistence-related whaling.

after the quotas were introduced in 1978, the number of whaling crews remained high, ranging from 82 in 1978 to 99 in 1980, and averaging 91 in the 1978-1982 period.

Bowheads were hunted along the Soviet coast as late as the early 1970's. The only Soviet kills during the study period, and the final reported kills in the Soviet subsistence hunt, were three bowheads taken in 1974 and two taken in 1975 (IWC in press). Table 5 does not list any spring subsistence whaling along the Soviet coast because the locations and seasons (spring or fall) of the 1974-1975 kills are not known to us.

Table 6. Number of bowheads struck during spring hunts in Alaska, 1974-1986.

Year	Savoonga	Gambell	Wales	Kivalina	Point Hope	Wainwright	Barrow	Total	Mean (n)	Source
1974	–[1]							44		Marquette et al. (1982)
1975								43		"
1976								78		"
1977	2	8	0	4	13	4	77	108		Marquette (1979)
1978	1	5	0	0	2	2	5	15		Braham et al. (1979)
1979	0	0	0	0	5	4	13	22		Braham et al. (1980b)
1980	2	4	1	0	1	1	20	31[2]		Johnson et al. (1981)
1981	3	3	0	2	5	3	9	25		Marquette et al. (1982)
1982	2	2	0	1	4	2	5	16		Dronenburg et al. (1983)
1983	1	1	1	0	4	2	7	16		Dronenburg et al. (1984)
1984	3	3	0	1	5	2	8	22		George and Tarpley (1986)
1985	2	2	1	0	3	2	6	16		"
1986	1	4	0	0	6	4	9	24		George et al. (1987)
1974-1986								460[2]	35.4 (13)	
1974-1977								273	68.2 (4)	
1978-1986	15	24	3	4	35	22	82	187[2]	20.8 (9)	

[1] Not known.
[2] Total increased by two to account for bowheads taken at Little Diomede and Shaktoolik (Johnson et al. 1981).

As noted earlier some bowheads occur near the village of Sachs Harbour (on Banks Island) during the spring season. Sachs Harbour hunters do. not hunt bowheads, and do not hunt from boats at this time of the year. Except for hunting activities pursued by residents of Little Diomede in Bering Strait (who have no bowhead quota), and walrus hunting by residents of St. Lawrence Island after they have filled their bowhead quota, virtually all subsistence-related vessel traffic in the western arctic during the spring season is associated with bowhead whaling activities in western and northwest Alaska.

Early Summer. --During the early summer period (mid June-July) much of the BBS is in Amundsen Gulf, with smaller numbers in the southeastern Beaufort Sea. The BBS is potentially exposed to subsistence-related vessel traffic from six settlements during this season (Table 5). Hunter and harvest statistics for these six communities are shown in Table 7. These statistics indicate that in 1988 there was a population of 5,735 residents, including 688 hunters, and that 180 hunters were active during the early summer period. These hunters took 497 ringed seals. The numbers of ringed seals may not directly reflect subsistence-related vessel traffic because some unknown portion of these seals may have been taken on fast ice or from floe edges. These situations would not require the use of boats, and the inclusion of these seals in the harvest statistics would tend to exaggerate the amount of subsistence-related vessel traffic during this season.

Table 7. Indices of subsistence-related vessel traffic calculated for villages with the potential to disturb BBS bowheads in early and late summer. Harvests are per year.

Village	Village Population Size[1]	Number of Hunters[2]	Number of Active Hunters[3]		Number of Belugas Harvested[4]		Number of Ringed Seats Harvested[3]	
			Early Summer	Late Summer	Early Summer	Late Summer	Early Summer	Late Summer
Sachs Harbour	158	50	11	12			42	70
Holman	303	76	49	34			448	363[4]
Paulatuk	193	63	24	27			7	5
Tuktoyaktuk	929	118	28	36			0	2
Inuvik	3,389	218	25	20			0	0
Aklavik	763	163	43	41			0	0
Total	5,735	688	180	170	127	10	497	440

[1] 1986 statistics from N.W.T. (1988).
[2] 1988 statistics (M. Fabijan, pers. comm.).
[3] Number of 1988 hunters who reported harvests during period (M. Fabijan, pers. comm.).
[4] Based on statistics and estimates from Fraker (1980), Norton Fraker and Fraker (1982) and Norton (1983), see text.

The few bowheads inhabiting the southeastern (Canadian) Beaufort Sea during early summer may be exposed to vessel traffic associated with beluga hunting in the Mackenzie estuary. Belugas are harvested in the Mackenzie Bay region beginning in late June or early July, depending on when ice conditions become suitable. During the nine years from 1974 to 1982, annual beluga harvests in this region ranged from 90 (1980) to 154 (1976) and averaged 127 (Norton 1983) (Table 7).

Belugas in this region are hunted by people from Aklavik, Inuvik, and Tuktoyaktuk. Norton and Fraker (1982) reported that roughly one-fourth to one-third of the Inuk families in Aklavik and Inuvik travel to establish campsites along the coast to hunt whales. This was estimated to be 267 people in 1977 (Fraker 1977). About 60% of Tuktoyaktuk families participate in one-day whaling excursions. Occasionally families from other communities travel to the Mackenzie estuary to hunt belugas. Norton and Fraker (1982) presented harvest dates for 436 of 480 white whales harvested during the 1978-1981 period. Fully 93% (404 of 436) of these whales were taken during the early summer (mid June-July) period, with peak harvests in July. Applying this ratio to the average harvest during the 1974-1982 period (127 whales) yields an estimate that an average of 118 (0.93 x 127) whales are taken in the Mackenzie estuary during the early summer period. Fraker (1980) suggested that an additional 10 whales may be harvested elsewhere each year in the Canadian western arctic. If we assume that 93% of these whales are taken during the early summer period, then the total harvest of belugas in the early summer range of the BBS would be 127 (118 + 9) individuals.

The beluga hunt in the Mackenzie estuary is an intensive activity involving many outboard-powered boats and rifles. However, the hunt occurs in very shallow estuarine waters that are not frequented by bowhead whales. In addition, because of the shallow water, underwater sound from the outboards would have high rates of transmission loss. Thus, it is doubtful that much, if any, noise from the beluga hunt reaches the few bowheads that occupy deeper water offshore from the Mackenzie Estuary during this season.

Late Summer.--In late summer the BBS is concentrated in the southeastern Beaufort Sea, although some of the stock is found in Amundsen Gulf and by early September some bowheads have moved into the eastern Alaskan Beaufort Sea. During this season bowheads are potentially exposed to subsistence-related vessel traffic from eight settlements (Table 5). In the Canadian western arctic belugas are harvested in low numbers (about 10) during the late summer season. Nearly all of these are taken in the Mackenzie estuary (Fraker 1980). Hunter and harvest statistics for the late summer period are shown in Table 7. These statistics show that in the late summer period 170 hunters harvested 440 ringed seals per year.

Residents of Kaktovik and Nuiqsut begin to hunt bowheads when they arrive in Alaskan waters in early September. Whalers from Barrow join the hunt later in September. The autumn hunt is from motorboats, in contrast to most of the spring hunt. The number of whales struck during the autumn hunt in Alaska ranged from O in 1975 to 13 in 1976 and averaged 4 over the 13 year period from 1974-1986 (Table 8). Since 1978, the year in which harvest quotas were introduced, the number of whales struck has ranged from 1 to 4 and has averaged 3. Overall, in terms of numbers of whales struck, the autumn hunt is on average about an order of magnitude smaller than the spring hunt. Only a small proportion of the total whales struck in the autumn hunt have been struck in our late summer period, i.e. prior to 16 September (Table 9). Only 23% (6 of 26) of the bowheads struck in the autumn hunt during the years 1978-1986 were struck during the late summer period. This low percentage is doubtless more related to the scarcity of bowheads in Alaskan waters near the whaling villages at this time of year than to lack of interest or effort on the part of the whalers. Hunting effort in terms of ready and active whaling crews is probably as high in early September as later in the season, because the arrival of bowheads is eagerly anticipated. Table 10 shows the number of whaling crews that participated in the autumn hunt from 1977 to 1981. Five to nine crews from Kaktovik and Nuiqsut hunted whales during this period. (Nuiqsut hunters sometimes join Kaktovik hunters because of unsuitable ice conditions near Nuiqsut.) In the years when Barrow whalers hunted, an additional 4-10 crews participated in the hunt.

Table 8. Number of bowheads struck during autumn hunts in Alaska, 1974-1986.

	Village					
Year	Kaktovik	Nuiqsut	Barrow	Total	Mean	Source
1974			-	7		Johnson *et al.* (1981)
1975			-	0		"
1976				13		"
1977	-	-	-	3		"
1978	3	0	0	3		Braham *et al.* (1980b)
1979	5	0	0	5		Johnson *et al.* (1981)
1980	3	0	0	3		Marquette *et al.* (1982)
1981	3	0	0	3		Dronenberg *et al.* (1983)
1982	2	1	0	3		Dronenberg *et al.* (1984)
1983	2	0	0	2		George and Tarpley (1986)
1984	3	0	0	3		"
1985	0	0	1	1		"
1986	3	1	0	4		George *et al.* (1987)
1974-1986	-			50	3.8 (13)	
1974-77				23	5.8 (4)	
1978-1986	*24*	*2*	1	27	3.0 (9)	

Table 9. Timing of the autumn bowhead harvest in Alaska, 1977-1986.

	Whales Struck				
Year	1-15 Sept.	After 15 Sept.	Unknown Date	Total	Source
1977	0	3	0	3	Marquette (1979)
1978	1	2	0	3	Braham *et al.* (1980b)
1979	0	5	0	5	Johnson *et al.* (1981)
1980	1	2	0	3	Marquette *et al.* (1982)
1981	2	1	0	3	Dronenberg *et al.* (1983)
1982	0	2	1	3	Dronenberg *et al.* (1984)
1983	0	1	1	2	George and Tarpley (1986)
1984	1	0	2	3	"
1985	0	1	0	1	"
1986	1	3	0	4	George *et al.* *(1987)*
Totals	*6*	20	*4*	30	

Table 10. Numbers of whaling crews participating in the autumn bowhead hunt, 1977-1981.

	Whaling Crews			
Year	Kaktovik and Nuiqsut	Barrow	Total	Source
1977	9	4-5	14	Marquette (1979)
1978	5*	10	15*	Braham *et al.* (1980b)
1979	“7	8-10	16	Johnson *et al.* (1981)
1980	5	0	5	Marquette et *al.* (1982)
1981	6	0	6	Dronenberg *et al.* (1983)

* The number of crews whaling at Nuiqsut was not noted. Thus, this is a minimum figure.

Autumn. --During this season some bowheads may be found until mid October in the western Canadian Beaufort Sea where they may be exposed to disturbance from subsistence-related vessel traffic from the communities of Tuktoyaktuk, Inuvik and Aklavik (Table 5). Belugas are not harvested at this time of the year. The bowhead hunt continues from the Alaskan villages of Kaktovik, Nuiqsut and Barrow until about mid October in some years. As noted earlier, most (77%) of the fall bowhead harvest occurs after 15 September, so most of the fall harvest occurs during the defined autumn season. Once the migrating bowheads pass Barrow they follow an offshore migration route across the Chukchi Sea.

In the early 1970’s bowheads were hunted along the Soviet coast. Within. our 1974-1986 study period, Soviet subsistence whalers took three bowheads in 1974 and two in 1975 (Marquette and Bockstoce 1980; IWC in press). Some or all of these kills may have been during autumn. Subsistence whalers at Sireniki, the Soviet settlement that took the most bowheads in 1940-1960, whaled in both the spring and autumn seasons. Although limited Soviet subsistence bowhead whaling occurred during the study period, autumn Soviet whaling is not indicated in Table 5 because the locations and seasons of the Soviet kills in 1974 and 1975 were not reported. Instead, Soviet settlements along the presumed autumn migration route are indicated as having the potential to disturb the BBS with other subsistence-related vessel traffic. Some bowheads may be exposed to disturbance from subsistence activities near the Diomedes in Bering Strait before they reach St. Lawrence Island as early as November (Johnson *et al.* 1981). Bowheads are not usually hunted from St. Lawrence Island in autumn.

Comparison of DSS and BBS Exposures

The levels of exposure to subsistence-related vessel traffic by the two stocks are compared below.

Bowheads have virtually no exposure to subsistence-related vessel traffic in either the DSS or BBS ranges during the winter season.

Bowheads in the DSS range have virtually no exposure to subsistence-related vessel traffic in the spring. In contrast BBS bowheads are the objects of intense hunting efforts in spring. During the 13 year study period, an average of 35 bowheads have been struck by whaler’s bombs each spring. An unknown additional number are disturbed by being chased by hunters or by hearing the sounds of the hunt. The number of whaling crews engaged in the spring hunt averaged 84 during the nine year period from 1974-1982. Thus, BBS bowheads are clearly subjected to more spring subsistence-related vessel traffic than are DSS whales.

In the mid June-July period, DSS bowheads are exposed to very little disturbance from subsistence-related vessel traffic. Most subsistence activities are restricted to floe edges, and the use of boats is infrequent. In the BBS range a very few bowheads may be exposed to vessel traffic associated with beluga hunting. However, most of the BBS is in Amundsen Gulf (where few belugas are taken) or far offshore in the Beaufort Sea during this season, so a relatively small portion of the BBS would be subjected to disturbance from the beluga hunt. A few bowheads may be disturbed by hunters involved in the ringed seal hunt in Amundsen Gulf. In conclusion, it seems that neither the DSS nor BBS is subjected to high levels of disturbance from subsistence-related vessel traffic in early summer, but levels are probably slightly higher in the BBS range.

In late summer, levels of subsistence-related vessel traffic in the DSS range are moderately high, with 366 hunters harvesting 324 small whales and 1,884 ringed seals per year. In the range of the BBS, hunter and harvest statistics are lower, with 170 hunters harvesting an estimated 10 belugas and 440 ringed seals per year. Some limited bowhead whaling occurs at Kaktovik during late summer with a total of between 6 and 10 bowheads struck in the years 1977-1986 (<1 per year). In conclusion, it seems likel y that subsistence-related vessel traffic levels are higher in the DSS range than in the BBS range in late summer, although it is only in the range of the BBS where there is direct hunting of bowheads themselves,

In the autumn, levels of boat-based vessel traffic are moderate in the range of the DSS, with more than 456 hunters harvesting 15 small whales and 2,228 ringed seals per year. In the BBS . range, the autumn bowhead hunt, while an order of magnitude smaller than the spring hunt in terms of the number of whales struck, is still substantial. The autumn hunt involves the use of large (7+ m) boats with high powered motors, in contrast to the skin boats propelled with paddles that predominate in the spring. For this reason, the spring and autumn hunts may constitute comparable levels of disturbance. Thus, the potential for autumn subsistence activities to disturb bowheads is higher for the BBS.

In summary, levels of subsistence-related vessel traffic in the BBS range appear to be higher than in the DSS range in spring, early summer and autumn. Levels appear to-be nil in both regions in winter, and higher in the DSS range in late summer.

Commercial Fishing

Data Sources

Levels of vessel traffic associated with commercial fishing in the DSS range were determined from fisheries statistics published by the Northwest Atlantic Fisheries Organization (NAFO). NAFO has published fisheries statistics for the Davis Strait and Baffin Bay regions for the years 1979-85. Some additional fisheries statistics compiled by the International Commission for the Northwest Atlantic Fisheries (ICNAF) are available for the years 1974-1978. The NAFO and ICNAF fishery statistics are derived from the reports of about 20 countries, including Canada and Greenland. Figure 9 shows the various subareas and divisions of the NAFO convention areas. The divisions relevant to the DSS are OA, OB, 1A, and 1 B. Information available for the two subareas (O and 1) included annual (1974- 1985) catches of all species of fish. In the case of subarea 1, however,

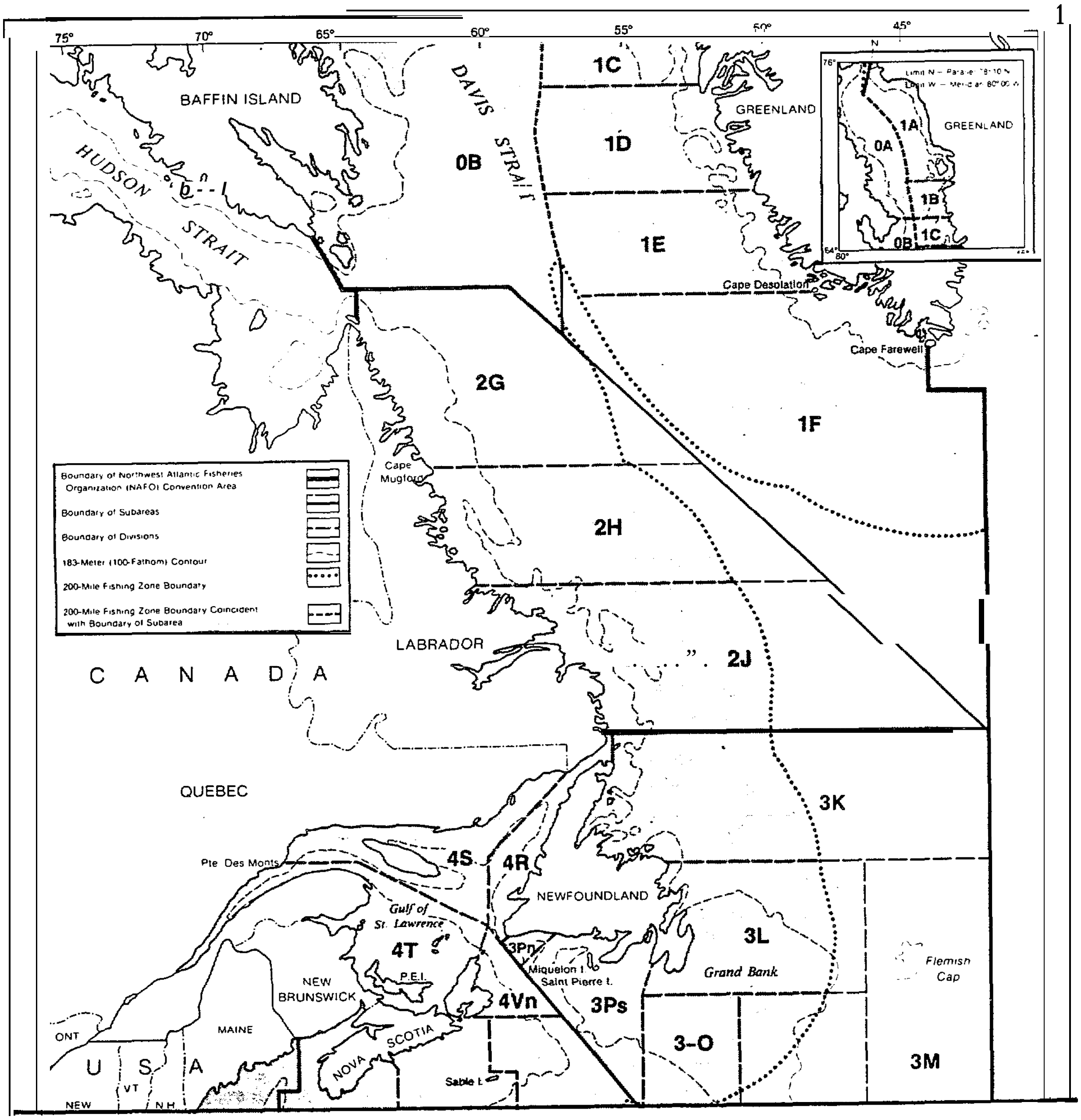


Figure 9. Map illustrating the boundaries of Northwest Atlantic Fisheries Organization (NAFO) subareas and divisions. (From NAFO 1984a.)

these statistics included catches in some divisions (1 C-1 F) outside the DSS range. In order to correct for this, catch statistics for the years 1979, 1982 and 1985 were analyzed in detail (NAFO 1984a,b; 1987). For those years, annual catches in the part of subarea 1 used by bowheads were determined by summing the catches reported for divisions 1A and 1B.

NAFO also produces annual statistics on fishing effort by vessel tonnage and month, for its various subareas and divisions. In order to determine the fishing effort (and potential disturbance to the DSS) represented by the annual catches, detailed analyses of the 1979, 1982 and 1985 fishing effort data were conducted. The NAFO fishing effort statistics included catch statistics by month and division, enabling us to correlate seasonal effort (days fished) with catch (tons caught). In the relatively few cases where effort data were missing, the missing values were estimated by extrapolating the overall effort : catch ratio in a given division and month to the appropriate catch data. This analysis facilitated the determination of fishing effort in terms of the number of vessel-days per season, We also calculated a daily average number of commercial fishing vessels present in the DSS range by dividing the vessels-days per season figures by the number of days in each season.

More detailed information exists concerning the distribution of Greenland's offshore fishing effort in the DSS range. The effort expended by the Greenland domestic fishery has been monitored by the Greenland Fisheries Department of the Ministry for Greenland, in Copenhagen. This data set is based on the activities of eight trawlers of about 700 tons each, owned and operated by the state company (The Royal Greenland Trade Department). The data base included the weekly number of hours trawled in each block of 7.5' latitude by 15' longitude. Data from the period January 1975-March 1980 were summarized and presented by four-week period for each block of 30' latitude by 30' longitude, with all years combined (Arctic Pilot Project 1981). The resulting maps show where fishing effort occurred, and how much effort (mean number of hours trawled) was expended in each block.

The Alaska Department of Fish and Game provided statistics concerning shellfish (1974-1986) and groundfish harvests (1974-1984) in the BBS range in Alaska's Bering Sea waters. We examined these statistics for the late autumn (November-December) and winter periods when BBS bowheads could be expected to be found in these waters. The data included the number of vessels, number of landings and weight of the catches by subarea and month. However, in some cases these data had been censored to protect the landing records of individual fishermen. When data for a particular subarea and month were censored, only the number of landings was available.

Results

DSS

Relatively little commercial fishing is conducted in Canadian portions of the DSS range. Although the NAFO convention area does not include the Canadian high arctic islands or Hudson Strait, it does include virtually all of the Canadian DSS range utilized by commercial fishing vessels. Experimental fishing cruises have been conducted in Ungava Bay in recent years and some freezer-trawlers have fished areas southwest of the northern tip of Labrador (M. Allard, Makivik Corporation, pers. comm.), but these activities occur during seasons when DSS bowheads are not present, The situation is quite different in the eastern half of Davis Strait, which is influenced by the northward flowing West Greenland Current. Stocks of Atlantic cod, northern prawn, Atlantic salmon and Greenland halibut are harvested by both a major domestic fishery in coastal and nearshore waters of W Greenland, and an international offshore fishery.

Table 11 presents the annual (1974-85) catches of all species of fish in NAFO subareas O and 1. Catches in subarea O (the western portion of Baffin Bay and Davis Strait) ranged from 1,000 to 10,000 metric tons per year. Catches in subarea 1 (eastern portion of Baffin Bay and Davis Strait, including areas south of the DSS range) were much higher, ranging from 92,000 metric tons in 1985 to 165,000 metric tons in 1979. We conducted detailed analyses of catch statistics from the years 1979, 1982 and 1985. For those years, annual catches in the divisions of subarea 1 in which DSS bowheads are found were determined by summing the catches reported for divisions 1A and 1 B. These figures (Table 11) suggest that catches in the eastern portion of the DSS range since 1979 have been fairly stable, ranging from 32,000 metric tons in 1982 to 44,000 metric tons in 1985. A detailed analysis of fishing effort in the DSS range, based on these three years, is presented below, by season.

Table 11. Nominal catches (in thousand metric tons) of all species in Northwest Atlantic Fisheries Organization Subareas O and 1.

	Subarea		
	0	1	
Year	0A-0B	1A-IF	IA + 1B
1974	4	115	N/D*
1975	·2	142	"
1976	8	132	"
1977	5	150	"
197s	1	128	"
1979	2	165	37
1980	3	126	N/D
1981	10	117	"
1982	6	127	32
1983	10	121	N/D
1984	3	101	"
1985	4	92	44

* Not Determined.

Winter. --During the winter season the number of vessel-days within the DSS range ranged from 302 in 1985 to 858 in 1979 (Table 12), Nearly all of the effort in each of the three years analyzed occurred in subarea 1. The sizes of the vessels involved in this fishery ranged from less than 50 tons to 500-999 tons. During the three years there were 955 vessel-days for which the tonnage of the vessels was noted. Most of the vessels were in the 150-499 ton (44%) and c50 ton (30%) classes. During the 90 day winter season the range of vessel-days observed (302-858) represents averages of 3.4 (1985) to 9.5 (1979) commercial fishing vessels present in the range of the DSS.

Spring. --During the April-mid June period of the three years examined, the number of commercial fishing vessel-days ranged from 702 in 1982 to 1,179 in 1979 (Table 12). Nearly all of this effort was in subarea 1. The tonnage of the vessels involved ranged from the <50 ton

Table 12. Commercial fishing effort in the DSS range by season and year.

Season	Divison (s) Considered	1979 Vessel-Days	1979 Vessel-Per Day	1982 Vessel-Days	1982 Vessels Per Day	1985 Vessel-Days	1985 Vessels Per Day	Mean Vessel-Days	Mean Vessels Per Day
Winter	OA 1A OB 1B	858	9.5	524	5.8	302	3.4	561	6.2
Spring	OA 1A OB 1B	1,179	15.5	702	9.2	833	11.0	905	11.9
Early Summer	O A - - -	38	0.8	50	1.1	13	0.3	34	0.7
Late Summer	O A - - -	73	1.6	70	1.5	113	2.5	85	1.9
Autumn	O A - O B -	337	3.1	446	4.2	468	4.4	417	3.9
Whole Year		1,792	4.9	1,792	4.9	1,729	4.7	2,002	5.5

category to the 1,000-1,999 ton classes. Most of the vessels were <50 tons (38%), 500-999 tons (30%), and 150-499 tons (27%). During the three 76 day spring seasons, the numbers of vessel-days recorded (range 702-1, 179) represented averages of 9.2 (1982) to 15.5 (1979) commercial fishing vessels present in the range of the DSS. Most were near the south edge of this range.

Early Summer. --Commercial fishing effort in division OA in the mid June-July period ranged from 13 vessel-days in 1985 to 50 vessel-days in 1982 (Table 12), The vessels involved were in the 150-499 ton and 500-999 ton categories. Sixty-six percent (67 of 101 vessel-days) of the fishing effort was from vessels in the 500-999 ton class. During the 46-day early summer seasons the average numbers of vessels present ranged from 0.3 (1985) to 1.1 vessels.

Some bowheads occupy the most northerly portions of division 1A in the early summer period. NAFO statistics indicate that substantial fishing effort occurs in division 1A during this season. This effort ranged from 474 vessel-days in 1979 to 888 vessel-days in 1982 and averaged 734 vessel-da ys per year in the years 1979, 1982 and 1985. All of the fishing effort reported by NAFO in these three years was attributed to Greenlandic vessels, Examination of the map summarizing the Greenland Fisheries Department effort data (Fig. 10) for the June-July period (1975-1979) clearly indicates that Greenland's fishing effort in the DSS range has been concentrated between 66 and 68"N latitude, several hundred miles south of the bowheads' early summer range. Most of the fishing effort depicted is in division 1B. Based on this geographical concentration of fishing effort by the state owned fishing fleet, it seems likely that most of the fishing effort expended by the private fleet in area 1A would be in the southern portion of that division. Thus, the potential for bowheads to be disturbed by fishing activities in division 1A during early summer seems very limited, and we have not included the early summer fishing effort in that division in Table 12.

Late Summer. --Commercial fishing effort in division OA during the August-mid September period ranged from 70 vessel-days in 1982 to 113 in 1985 (Table 12). These fishing vessels ranged from the 50-149 ton category to the 1000-1,999 ton category. Of the vessels whose tonnage was specified, 41% (106 of 256 vessel-days) were in the 1,000-1,999 ton category. The next most frequent vessel size was the 500-999 ton category (33%). The numbers of vessel-days recorded in the 46-day late summer seasons represent averages of 1.5 to 2.5 vessels present at a time.

Autumn.--Commercial fishing effort in the mid September-December period during the three years ranged from 337 vessel-days in 1979 to 468 in 1985 (Table 12). This effort was distributed between NAFO divisions OA and OB. The sizes of the fishing vessels ranged from the 50-149 ton category to the >2000 ton class. Of the 1,251 vessel-days whose vessel tonnage was specified there were 35% in the 500-999 ton class, 33% in the 2,000+ ton class, and 2170 in the 50 to 149 ton class. The numbers of vessel-days recorded in the 107-day autumn seasons represent averages of 3.1 to 4.4 fishing vessels present in the DSS range.

Summary, --Based on the mean figures for the three years we examined, it is apparent that the spring season is the season when commercial fishing vessels have the most potential to disturb DSS bowheads. In terms of both the average number of vessel-days (905) and the average number of vessels present (1 1.9), the spring season supports the most fishing effort in the DSS range. The early summer season is the season with the least fishing effort (34 vessel-days and 0.7 vessels). For the year as a whole, there was an average of 2,002 vessel-days in the range of the DSS, which is the equivalent of 5.5 fishing vessels present in the range of the DSS.

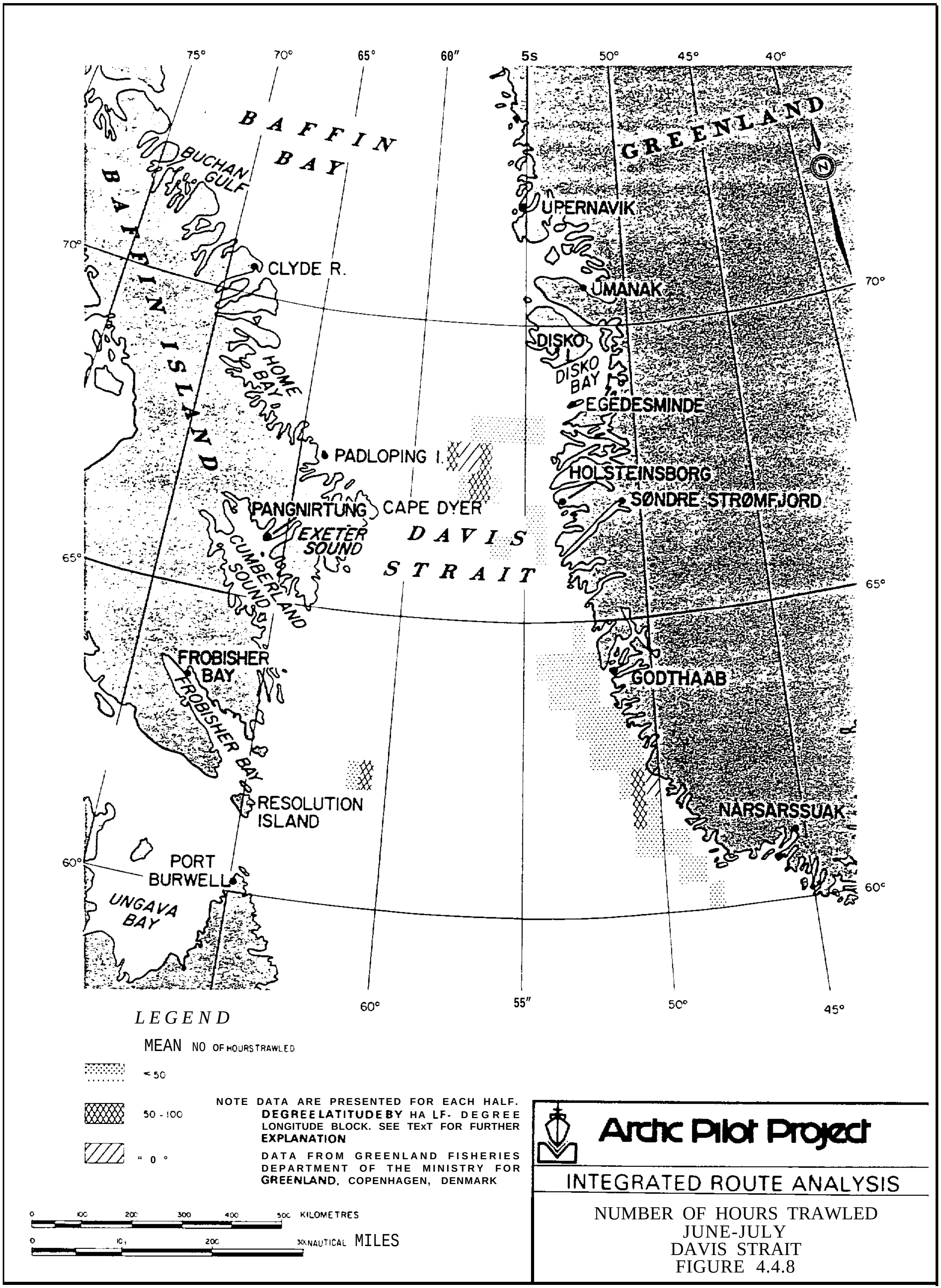


Figure 10. Fishing effort by Royal Greenland Trade Department trawlers (from APP 1981),

These data suggest that there is considerable potential for DSS bowheads to be disturbed by fishing vessels, especially in spring. Flowever, actual instances of disturbance are probably not very frequent. The bowhead population is widely dispersed during most seasons, and much of the population will generally be far from any fishing vessels. This is especially true because during many seasons (e.g., winter and spring) bowheads tend to occur in parts of their range that contain heavy pack ice. This type of ice cover is inimical to the activities of fishing vessels and probably greatly limits the potential for bowheads to be disturbed by fishing vessels.

BBS

BBS bowheads are unlikely to be disturbed by commercial fishing vessels in spring, early summer or late summer because of the severity of ice conditions in spring, and the absence of any offshore commercial fishing operations in the BBS's summer range. Statistics provided by the Alaska Department of Fish and Game concerning shellfish (1974-1986) and groundfish (1974-1984) fisheries in Alaskan Bering Sea waters suggest that levels of fishing activity in the BBS's Alaskan Bering Sea range are very low in autumn and nil in winter. During the 13 year study period, fishing vessels were recorded in late autumn in the BBS's Alaskan range only in 1983 (November) and 1985 (December). A single landing of tanner crabs was recorded in each of these months. No commercial fishing activities were recorded during winter in the Alaskan portion of the BBS's winter range. We do not have any information about commercial fishing activities in autumn or winter in Soviet portions of the BBS's autumn and winter ranges. However, the tendency of bowheads to winter in areas of pack ice makes it very unlikely that they would be exposed to disturbance by fishing vessels in winter.

Comparison of DSS and BBS Exposures

Levels of commercial fishing activity with the potential to disturb bowheads are clearly higher in the DSS range than in the BBS range in spring, early summer, and late summer. For the autumn and winter seasons we have incomplete information for the BBS. However, the available data suggest that, in autumn, levels of commercial fishing in the range of the BBS are very low, while levels in the DSS range are moderate (average of 3.9 vessels). In winter, commercial fishing does not occur in Alaskan portions of the BBS's winter range while an average of 6.2 vessels occur in the DSS range in winter. Without data for Soviet waters during autumn and winter it is not possible to conclude that fishing levels are higher in the DSS range during these seasons. Also, in most seasons it is likely that fishing tends to be concentrated in parts of the seasonal range where bowheads are scarce, given the affinity of bowheads for ice. However, it does seem very likely that, in the course of a year, DSS bowheads are potentially exposed to more disturbance from commercial fishing vessels than are BBS bowheads.

Marine Seismic Activity

Data Sources

DSS

Marine seismic programs in the eastern Arctic have been conducted by geophysical companies on behalf of petroleum exploration companies and by research vessels operated by research institutions funded by the Canadian Government. We have termed the former 'Industry' seismic and the latter 'Research' seismic, Information about Canadian Industry seismic activities is collected and maintained by the Canadian Oil and Gas Lands Administration (COGLA), a branch of Energy, Mines and Resources Canada (EMR). Information about Research seismic activity is maintained by the Atlantic Geoscience Centre (Dartmouth, N.S.), another branch of EMR. Information about seismic activities in W Greenland waters is archived by the Geological Survey of Greenland, Copenhagen, Denmark.

The underwater sounds produced by air guns used for seismic exploration are very strong and they propagate for long distances (Greene and Richardson 1988). Thus, seismic exploration can potentially be heard by bowheads at long distances. We have assumed that seismic exploration within 100 km of the seasonal range of the DSS could affect these bowheads.

Industry Seismic. --Geophysical projects conducted in Canada's 'Frontier Lands' since 1973 are listed in COGLA (1988). These frontier lands include all Canadian portions of the DSS range. We compiled a list of 84 geophysical projects that appeared to have been conducted within the DSS range during the 1974-1986 period. Information was obtained from project reports maintained by COGLA'S Data Management Division, Resource Evaluation Branch, on the timing, locations, and lengths of seismic lines shot during those projects, The reports varied widely in their completeness. Some consisted only of seismic sections or shot point maps. Some reports were 'interpretations' of data from lines shot prior to 1974. Others consisted of operations reports with detailed maps and daily summaries of the number of kilometers of seismic lines shot. In the few cases when a project report could not be located, we used the number of km of seismic lines as listed in COGLA (1988).

Some assumptions were invoked to summarize the data presented in project reports, These reports frequently presented the total km of seismic shot over the length of the project, without a daily breakdown. If the project was conducted over more than one season (e.g., late summer and autumn), it was assumed that the number of km shot during each season was proportional to the number of days of project activity within each season. Occasionally, deductive reasoning was used to infer missing information. For example, sometimes the timing of a project was not specifically mentioned, other than that the seismic survey was conducted in the 'fall of 1978'. If we knew, from our analysis of other reports, that the ship that conducted that survey was working on other commitments all autumn except for a two week period in late September, we assumed that the survey in question was conducted during that two week period.

Information about 12 seismic programs shot in W Greenland waters during the years 1974-1986 was provided by the Ministry of Energy, Mineral Resources Administration for Greenland. Maps of the seismic lines shot were provided for all of the projects. However, dates of operation were not available for four of the projects.

Research Seismic .--The levels of 'research' seismic were evaluated from a number of sources. The Atlantic Geoscience Centre (AGC) provided brief descriptions of the 39 cruises that included seismic exploration in the general range of the DSS during the 1974-1986 period. These descriptions included the year, cruise number, name of the vessel, and types of seismic equipment used. The AGC also provided a plot of each year's seismic tracks and the total km of seismic lines shot on each cruise.

During the 13 year study period (1974-1986), marine seismic was shot in the DSS range by the *Hudson* during 11 years, the *Baffin* during three years, and by *Pandora II* and *Des Groseilliers* during one year each. The *Hudson* and *Baffin* are research vessels operated by the Bedford Institute of Oceanography (BIO). We visited BIO in Dartmouth, N. S., in spring 1989 and examined ship's logs of the *Hudson* and *Baffin*. We extracted the daily positions of these ships when they were in the range of the DSS and also recorded the days when it was noted in the ship's logs that the vessels were shooting seismic. Positions for *Pandora II* and *Des Groseilliers* were listed in Transport Canada ECAREG printouts (described later in this report, see 'Commercial Vessel Traffic '). Using these sources of information the seismic lines plotted from the AGC database were correlated with the position-date data extracted from ship's logs and ECAREG printouts. The portion of each cruise's seismic lines that were shot in areas and during seasons with the potential to influence DSS bowheads was determined.

BBS

Information about seismic activity in the BBS range was obtained from a number of sources. The most detailed information was provided by Brouwer et *al.* (1988). These authors summarized the number of km of seismic lines shot in the Canadian Beaufort Sea, by 10-day periods, for the years 1980-1986 and included the marine seismic surveys conducted by both 'industry' and 'research' vessels. In most years the coverage period was 1 August- 1.0 September, although in some years 10-day periods prior to August and after 10 September were included. The 1 August-10 September coverage period is five days short of the late summer period (1 August-15 September) used in the present study. To 'correct' the Brouwer *et al. (1988)* data we assumed that seismic during the 11-15 September period would be equivalent to half of that during the 1-10 September period. Thus, the late summer figures presented here are the data from 1-31 August plus 1½ times the 1-10 September values. (In the relatively few cases [1984-1986] where data for 11-20 September were available, we added half of that figure to the 1 August-10 September figure.)

Information about early seismic activity in the Canadian Beaufort Sea (including Amundsen Gulf) was available for the years 1974-1982 from COGLA (1988). This publication lists marine seismic programs conducted by various geophysical companies and the number of km of seismic lines associated with these programs, although it does not indicate the time of year that the seismic programs were conducted. We corrected for this by applying the late summer : autumn ratio shown in Brouwer *et al.* (1988) for the years 1985 and 1986 to these data, In 1985, 89.5% (1,191 of 1,330 km) of the seismic lines were shot during the late summer period. In 1986, 79.3% (3,109 of 3,922 km) of the seismic lines were shot in late summer. The average percentage of seismic shot *in* late summer in these two years was 84.4%. We applied this figure to the annual totals derived from COGLA (1988) for the years 1974-1979 to estimate the number of km shot during the late summer period in those years.

The U.S. Minerals Management Service provided information about marine seismic permits issued for seismic exploration in the Alaskan Beaufort and Chukchi Seas for the years 1974-1986. This information included the names of the permittee and contractor and a listing of the types of data acquired in the programs. Information about the numbers of seismic vessels operating in autumn was obtained from a number of sources, including Reeves et *al.* (1983b), Ljungblad *et al.* (1984b, 1985), Fraker *et* al. (1985), Richardson *et al.* (1985a) and Brouwer *et al.* (1988). Halliburton Geophysical Services (formerly GSI) and Western Geophysical Company (WGC) provided lists of the seismic vessels that they operated each autumn in the Beaufort and Chukchi Seas during the 1974-1986 period. For each of these two companies we determined the number of seismic vessels operating in the Beaufort Sea after 15 September, and the number operating in the Chukchi Sea after 30 September. Information on the numbers of km of seismic shot in U.S. waters was not available.

Results

DSS

Industry Seismic.--In this section the results of our assessment of industry seismic in the DSS range are summarized by year and season.

1974. We examined 13 reports of geophysical projects conducted in Canadian waters during 1974. Seven of those concerned interpretation or reprocessing of seismic surveys conducted in prior years, or were reports of seismic surveys conducted outside the range of the DSS. The six seismic surveys relevant to the DSS are listed in Appendix 1. A total of 2,195 km of seismic was conducted in late summer and 3,718 km in autumn (Table 13).

Table 13. Estimated number of km of 'Industry' seismic with the potential to influence DSS bowheads, 1974-1986.

Year	Late Summer	Autumn	Total
1974	2,195	3,718	5,913
1975	5,078	11,285	16,363*
1976	1,606	4,948	6,554
1977	1,471	657	2,128
1978	2,721	3,869	6,590
1979	761	6,062	6,823
1980	0	1,150	1,150
1981	18	2,384	2,402
1982	0	0	0*
1983	0	0	o
1984	0	0	0
1985	0	0	0
1986	0	0	0
1974-1986	13,850	34,073	47,923

* Minimum figures--see text.

1975. We examined 29 reports of geophysical programs conducted in Canadian waters in 1975. Of these, 17 concerned the interpretation or reprocessing of old data and one report described a seismic program shot on sea ice during a period when bowheads would not be present. Of the remaining 11 reports, nine were relevant to the DSS and are listed in Appendix 1. These projects resulted in 5,078 km of seismic during late summer and 11,285 km during autumn, for a total of 16,363 km (Table 13). Two reports contained maps and/or seismic profiles, but no text. Without text it was not possible to determine whether these projects involved the interpretation and/or reprocessing of old seismic data, or whether they represented new geophysical programs shot in 1975. COGLA (1988) indicates that these projects were associated with 5,427 km of seismic. Some of these lines may have been shot in 1975 in the DSS range, when the DSS was present. We have not included these reports; therefore, the totals shown in Table 13 should be regarded as minima.

Six seismic programs were conducted in W Greenland waters in 1975. Three programs shot during the earl y and late summer periods were conducted south and east of the DSS's summer range. Another program, shot during the autumn period, was south of the DSS's autumn range. Two programs were shot for which little information is available. Maps show the seismic lines shot, but the time of year when they were shot is not indicated. However, the lines shot in both programs were south of the summer range and east of the autumn range of the DSS. Thus, none of the Greenland programs had the potential to disturb DSS bowheads.

1976. Twelve projects were conducted in Canadian waters during 1976. One of these was shot on sea ice during a period when the DSS would not be present. The remaining 11 projects are listed in Appendix 1. A total of 1,606 km of marine seismic was shot during late summer and 4,948 km were shot in autumn. Two seismic programs were conducted off W Greenland in 1976, both outside the DSS's range.

1977. Four of five Canadian projects from 1977 were conducted in the DSS range (Appendix 1). Three seismic programs were conducted off W Greenland in 1977, all south of the DSS'S range. Within the DSS range, 1,471 km were shot during the late summer period and 657 km during the autumn period for a total of 2,128 (Table 13).

1978. Seven reports of Canadian projects were available for 1978. Three involved the interpretation or reprocessing of seismic shot in other surveys. The remaining four seismic surveys are listed in Appendix 1. One seismic program was shot off W Greenland in 1978, east of the DSS'S autumn range. In total 2,721 km (including 234 km of high resolution seismic) were shot during late summer, and 3,869 km (including 319 km high resolution) were shot in autumn for a total of 6,590 km (Table 13).

1979. We examined reports of 10 marine seismic projects conducted in Canadian waters in 1979. Five of these were high resolution, well-site surveys conducted in Davis Strait during the early summer and late summer seasons when bowheads do not occur in Davis Strait. Two programs shot in Davis Strait (63 "N, 59°W) in May and June were well south of the DSS's late spring range. Thus, only three of the 10 Canadian seismic projects had the potential to influence DSS bowheads (Appendix 1). During the late summer period 761 km of seismic were shot, and during the autumn period 6,062 km were shot, for a combined total of 6,823 km with the potential to influence DSS bowheads (Table 13).

1980. Three projects were conducted in eastern Canadian waters in 1980. One was strictly a side-scan sonar and bathymetric study. Details about the remaining two reports are presented in Appendix 1. These two projects resulted a total of 1,150 km of marine seismic during the autumn period. This total included 381 km of marine dynamite refraction survey. A report about a fourth project from 1980 could not be located. This report pertained to 708 km of seismic shot in Davis Strait. Without seeing the report it is not possible to determine whether the project involved the interpretation and/or reprocessing of old data, or whether it described a new seismic program conducted in 1980. If it was new seismic shot in 1980 it may or may not have been a source of disturbance to the DSS, depending on the time of year it was carried out. The report is not included in Table 13.

1981. There were two reports of seismic projects conducted in eastern Canadian waters in 1981. One was an interpretation report of a seismic survey shot in a prior year. The other report described a seismic reflection and refraction survey shot in 1981 (Appendix 1). During the late summer period 18 km of seismic reflection survey were shot. During autumn, 1,553 km of seismic reflection and 831 km of seismic refraction were shot for a total of 2,384 km. For the year, 2,402 km of reflection and refraction seismic were shot (Table 13).

1982. We examined two of three reports of seismic programs conducted in eastern arctic waters in 1982. Two reports described surveys conducted in the Davis Strait region (early and late summer) when bowheads were unlikely to be present. The third report, concerning 2,447 km of seismic survey, could not be located. This report may have described the interpretation or reprocessing of seismic data acquired in an earlier year or it may have described a new 1982 survey. The dates and locations of the survey are not known. Because of this uncertainty, the figure (0) shown in Table 13 should be regarded as a minimum.

1983-1986. COGLA (1988) lists geophysical programs completed before 31 October 1982. However, the Database Manager at the Resource Evaluation Branch of COGLA in Ottawa stated that, to his knowledge, no industry marine seismic had been conducted in the DSS study area since 1982 (Rudi Klaubert, pers. comm.). No industry marine seismic was shot in Greenland's DSS waters during these years.

During the 13 year period 1974-1986, at least 47,923 km of Industry seismic were shot at times and places where DSS bowheads might have been exposed to the noise. All of these seismic lines were shot during the first eight years (1974- 198 1) of this period. All of this seismic was shot during late summer and autumn, with most (71. 1%) in autumn.

Research Seismic. --The results of the assessment of research seismic exploration levels in the DSS area are shown in Table 14. A total of 2,181 km of seismic surveys were shot in the range of the DSS during seasons when bowheads could be influenced, an average of 168 km/year. During the 13 year study period the annual totals ranged from O in 1979 and 1984, to 496 km in 1980. All of the research seismic with the potential to disturb DSS bowheads was shot during the late summer (36%) and autumn (64%) periods.

Table 14. Estimated number of km of 'Research' seismic with the potential to affect DSS bowheads, 1974-1986.

Year	Late Summer	Autumn	Total	Vessel(s)
1974	41	21	62	*Hudson*
1975	0	0	0	
1976	78	50	128	*Hudson*
1977	51	74	125	*Hudson*
1978	42	94	136	*Hudson*
1979	0	0	0	
1980	55	165	220	*Hudson, Baffin*
1981	0	227	227	*Hudson, Pandora II*
1982	0	147	147	*Hudson*
1983	115	381	496	*Hudson, Baffin*
1984	0	0	0	
1985	152	139	291	*Hudson, Des Groseilliers*
1986	257	92	349	*Hudson, Baffin*
Total	791	1,390	2,181	

Summary .--Combining the figures for Canadian and Greenland Industry seismic programs with figures for Research seismic programs, a total of at least 50,104 km of seismic lines with the potential to disturb DSS bowheads were shot during the 1974-1986 period (Table 15). All of this seismic was shot in the late summer and autumn periods, and most (70.8%) was shot during autumn. The number of km of seismic shot each year ranged from O in 1984 to at least 16,363 km in 1975, and averaged at least 6,854 km per year. There was a marked decline in levels of seismic exploration after 1981, when industry seismic ceased to be conducted in the range of the DSS. During the 1982-1986 period an average of only 257 km/year was shot compared to at least 6,103 km/year in the 1974-1981 period,

Table 15. Estimated number of km of Industry and Research seismic with the potential to affect DSS bowheads, 1974-1986.

Year	Late Summer	Autumn	Total
1974	2,236	3,739	5,975
1975	5,078	11,285	16,363
1976	1,684	4,998	6,682
1977	1,522	731	2,253
1978	2,763	3,963	6,726
1979	761	6,062	6,823
1980	55	1,315	1,370
1981	18	2,611	2,629
1982	0	147	147
1983	115	381	496
1984	0	0	0
1985	152	139	291
1986	257	92	349
Totals	14,641	35,463	50,104

The number of operating seismic vessels is another useful index of seismic activity. The minimum number of seismic vessels operating in the DSS range during autumn is shown in Table 16. The inclusion of research vessels in this table overstates DSS seismic activity levels because these vessels were not full time seismic ships. The 21 industry 'vessel-seasons' listed in Table 16 resulted in an average of 2,282 km of seismic per vessel-season, compared to an average of only 155 km for each of the 14 research vessel-seasons.

BBS

The amounts of seismic survey activity in the range of the BBS bowheads are evaluated in various ways in the following sections. Because the types of data available for different seasons and years were not complete or consistent, a number of different measures of marine seismic activity were used. These measures include the number of km of seismic surveys, the number of operating seismic vessels, the number of vessels operating for specific companies, and the number of marine seismic exploration permits issued by the U.S. Minerals Management Service.

Table 16. Number of seismic vessels operating in the range of the DSS during autumn.

Year	Industry	Research	Total
1974	3	1	4
1975	5	0	5
1976	3	1	4
1977	2	1	3
1978	2	1	3
1979	2	0	2
1980	2	2	4
1981	2	2	4
1982	0	1	1
1983	0	2	2
1984	0	1	1
1985	0	2	2
1986	0	0	0
Totals	21	14	35

Winter and Spring. --Because of the severe ice conditions encountered in the BBS's winter and spring ranges, no marine seismic activity has been conducted by seismic vessels during these seasons. Ice-based seismic exploration occurs on landfast ice during late winter, but does not occur at places and times when bowheads would be present.

Early Summer. --During the mid June-July period, the BBS is found primarily in Amundsen Gulf and the Canadian Beaufort Sea. Although we do not have specific information about seismic activities in the Amundsen Gulf region, the vast majority of seismic exploration in the BBS's summer range has been conducted farther west in the Canadian Beaufort Sea. It is likely that there has not been any seismic exploration in Amundsen Gulf during the summer months.

Information about seismic activity in the Canadian Beaufort Sea during the early summer is available for only a few of the years within the 1974-1986 study period (Brouwer *et al.* 1988). Data are available for the 22-31 July 1981 period, the 11-31 July 1984 period and for the entire early summer periods of 1985 and 1986. No seismic activities were reported in the early summer periods of 1985 and 1986. Seismic activities were reported for the partial early summer periods recorded in 1981 and 1984 (Table 17). Based on these few data, it is evident that some limited seismic activity begins in the latter part of the early summer period in some years.

Late Summer. --Data on seismic activity in the BBS range during the August-mid September period are presented in Table 17. In total at least 45,664 km of seismic surveys were conducted in the 13 year period 1974-1986. Because not all seismic lines were documented in some years, this figure is a minimum. The levels of seismic activity ranged from at least 1,191 km in 1985 to at least 6,917 km in 1979 and averaged at least 3,513 km/year over the 13 year period (Table 17).

Table 17. Minimum seismic activity in the Canadian Beaufort Sea, 1974-1986.

Year	Number of Kilometers of Seismic Surveys: Early Summer	Late Summer	Autumn*
1974		1,805	-
1975		2,244	-
1976	-	2,219	-
1977		2,412	
1978		4,431	
1979		6,917	
1980	-	3,158	
1981	863[2]	6,304	
1982	-	4,040	
1983		4,287	-
1984	304[3]	3,547	628[4]
1985	0	1,191	139
1986	0	3.109	813
1974-1986 total	-	45,664	
1974-1986 mean	-	3,513	

[1] 16 September-15 October period only.
[2] 22-31 July period only.
[3] 11-31 July period only.
[4] 16-30 September period only.

Brouwer *et al.* also recorded the number of seismic vessels operating in the Canadian Beaufort Sea during the 1 August-1 O September period. The numbers of vessels ranged from one (1986) to five (1983) and averaged 3.1 during the 1980-1986 period.

Autumn. --The BBS has a wide distribution during the mid September-December period and occupies Canadian, Alaskan and Soviet waters. Some bowheads occupy the Canadian Beaufort Sea until as late as mid October. Limited data are available concerning seismic activity in the Canadian Beaufort Sea for the 16 September-15 October period. Data are available for the 16-30 September period of 1984 and the entire 16 September-15 October periods of 1985 and 1986. The data from these three years suggest that levels of autumn seismic activity in the Canadian Beaufort Sea have been low; the 1985 and 1986 autumn seismic activity represented only 12 and 26%, respectively, of the levels documented for the late summer periods of those years. If these percentages are representative of the years 1974-1984, then in most years fewer than 1,000 km of seismic surveys were conducted in autumn in the Canadian Beaufort Sea.

It was not possible to determine the number of km of marine seismic lines shot in the Alaskan Beaufort and Chukchi seas. However, information on the numbers of marine seismic exploration permits issued by the Minerals Management Service was available. The number of permits issued in a year does not directly indicate autumn levels of seismic exploration, but does provide a general indication of the levels of seismic survey activity. The number of permits issued in 1974-1986 ranged from one in 1980 to 19 in 1983. The figures in Table 18 suggest that seismic exploration in the Alaskan Beaufort Sea proceeded at moderate levels in the years 1974-1980. Permits were first issued for the Chukchi Sea in 1981 and the combined Alaskan Beaufort and Chukchi permits indicate relatively high levels of exploration in the years 1981-1986.

Table 18. Numbers of seismic exploration permits issued by the U.S. Minerals Management Service, 1974-86.

Year	Beaufort Sea	Chukchi Sea	Total
1974	2	0	2
1975	4	0	4
1976	5	0	5
1977	3	0	3
1978	3	0	3
1979	2	0	2
1980	1	0	1
1981	5	2	7
1982	11	0	11
1983	14	5	19
1984	14	3	17
1985	7	5	12
1986	2	4	6
Totals	73	19	92

In the absence of information on the numbers of km of seismic surveys, we examined the numbers of seismic vessels that operated in the BBS range in autumn. Information was provided by the two major geophysical operators in the Arctic: Halliburton (formerly Geophysical Services Inc.) and Western Geophysical Company. These two companies were listed as the contractors in 67.4% (62 of 92) of the marine seismic permits granted by MMS from 1974-1986. For each company, we determined the number of seismic vessels which operated in the Beaufort Sea after 16 September, and the number operating in the Chukchi Sea after 30 September (Table 19). These data show a gradual increase from a low of two vessels in 1974 to a high of 11 vessels in 1985, The figures should be regarded as minima since not all of the marine seismic projects in the region were conducted by GSI and WGC. However, our examination of reports that documented the seismic vessels operating in the BBS range in autumn in the years 1981-1984 failed to find any mention of active seismic vessels that were not included in the GSI and WGC data (Reeves *et al.* 1983b; Ljungblad et *al.* 1984b, 1985; Fraker *et al.* 1985).

We have no information about the amount of marine seismic exploration (if any) in the Soviet part of the autumn range of the BBS.

Table 19. Approximate numbers of seismic survey vessels operating in the BBS range by year and season.

		Autumn		
Year	Late Summer[1]	GSI[2]	WGC[3]	Total
19'74	-[4]	1	1	2
1975	·	1	2	3
1976		1	2	3
1977		1	2	3
1978		1	3	4
1979		1	3	4
1980	2	2	3	5
1981	3	3	3	6
1982	3	2	4	6
1983	5	5	5	10
1984	4	5	5	10
1985	4	6	5	11
1986	1	3	4	7
Totals	22	32	42	74

[1] Period 1 August to 10 September.
[2] Ships operated by Geophysical Service Inc. (GSI) *(now* Halliburton).
[3] Ships operated by Western Geophysical Company.
[4] No data.

Comparison of DSS and BBS Exposures

Winter and Spring

No winter or spring marine seismic activity was recorded in the DSS or BBS ranges during the 13 year study period.

ar m

Information about marine seismic activity during the early summer period was available for both the DSS and BBS for the years 1981, 1984, 1985 and 1986. No seismic activity was recorded during any of these four years in the DSS range. Seismic activity was recorded in the BBS range in 1981 and 1984 (Table 20). Thus, the data suggest that more seismic has been shot in the BBS range than in the DSS range during early summer.

Table 20. Comparison of relative levels of marine seismic activity in the ranges of the DSS and BBS, by season, 1974-86.

	Early Summer		Late Summer		Autumn	
Year	DSS	BBS	DSS	BBS	DSS	BBS
1974			+		+	
1975			+		+	
1976				+	0	0
1977				+		+
1978				+		+
1979				+		+
1980				+		+
1981		+		+		+
1982				+		+
1983				+		+
1984	-	+		+-		•+
1985	0	0		+		+
1986	0	0	0	0		+
1974-1986	0	2	2	11	2	10

[1] 'O' = no difference in relative levels of marine seismic activity,
[2] '+' = relatively higher levels of marine seismic activity.
[3] '-' = relatively lower levels of marine seismic activity.

Late Summer

During the late summer of 1974-1986, more seismic was shot in the BBS range than in the DSS range during 11 of 13 years (Table 20). In total, more than three times as much seismic was shot in the BBS range than in the DSS range (45,664+ km vs. 14,641+ km). The only years when substantial y more seismic was shot in the DSS range were the years 1974-75.

Autumn

There was much marine seismic exploration in the range of the DSS in 1974-1979 (Tables 13, 21). An average of 5,130 km per year was shot during the autumns of these six years. In the seven years from 1980-1986, seismic survey activity decreased substantially in the DSS range, averaging only 669 km per year, all of it by research vessels after 1981.

The data for the BBS range are not as clear cut, but they show a gradual increase from moderate levels in the mid 1970's to much higher levels in the mid 1980's. The number of operating seismic vessels is the only direct comparison available between the DSS and BBS. The vessel data show that in the years 1977-1986 more seismic activity was conducted in the range of the BBS than in the range of the DSS. The data show that more seismic activity may have occurred in the DSS area than in the BBS range in 1974-75. We have assumed that seismic levels

Table 21. Comparison of indices of seismic survey activity in autumn within the ranges of DSS and BBS bowheads, 1974-1986.

	DSS	BBS	
Year	No. of Industry Seismic Vessels	No. of MMS Permits Issued	No. of GSI and WGC Seismic Vessels
1974	3	2	2
1975	5	4	3
1976	3	5	3
1977	2	3	3
1978	2	3	4
1979	2	2	4
1980	2	1	5
1981	2	7	6
1982	0	11	6
1983	o	19	10
1984	0	17	10
1985	0	12	11
1986	0	6	7

in the two regions were approximately equal in 1976. Thus, we conclude that seismic activity levels were higher in the BBS region in 10 years, lower in two years, and approximately equal in one year (Table 20).

Conclusions

In total there were 27 season/year comparisons where relative levels of marine seismic activity appeared to differ markedly between the DSS and BBS. In 23 of these 27 cases (85%), levels were higher in the BBS (Table 20). During the late summer season, when a direct quantitative comparison could be made, the total seismic shot in the BBS range was more than three times the amount shot in the DSS range. Overall, the data suggest that seismic activity levels were higher in the DSS range in the first two years of the study period, but higher in the BBS range in the remaining 11 years of the period. This comparison excludes any seismic exploration that may have occurred 'in Soviet waters. If there was marine seismic work there in autumn, the disparity between the BBS and DSS would be even greater.

Commercial Vessel Traffic

As defined here, commercial vessel traffic includes the types of vessel traffic that have not been discussed earlier in the report. Commercial traffic includes many types of vessels, among them freighters, small tankers and barge convoys involved in the re-supply of northern communities; drillships, dredges and associated support vessels involved in offshore exploration for oil and gas; cruise ships and research vessels. In DSS waters, passenger vessels transit the coastal waters of West Greenland and ice-strengthened ore carriers transport concentrated mineral ores from arctic

West Greenland and ice-strengthened ore carriers transport concentrated mineral ores from arctic mines to European ports. A small amount of crude oil is shipped by ice-strengthened tanker from a production facility on Cameron Island in the High Arctic. Many of these vessels are assisted and supported by Canadian Coast Guard icebreakers, which constitute a substantial portion of the vessel traffic in the DSS range.

Data Sources

DSS

Information about commercial shipping in the Canadian range of the DSS was obtained from Transport Canada's ECAREG database. Transport Canada provided records for the years 1980-1986 of all vessels that showed a Canadian arctic port as its port of departure or destination. The records included the name of the vessel, vessel type, gross tonnage, main cargo, port of departure, destination port, and date, time and position. The frequency of position reporting varied considerably. Coast Guard icebreakers usually reported several positions a day, Merchant vessels usually reported positions once a day or less frequently. Overall, in the seven year period vessels spent 3,844 days (including some days in port) in the DSS range during seasons when there was potential for detection by bowheads. Positions were reported for only 2,648 (69%) of these days. The lack of daily positions precluded accurate mapping of vessel routes; therefore, DSS vessel traffic by season was assessed in terms of number of vessel-days and number of vessels. Records for research vessels were sometimes not included in the ECAREG records, presumably because these vessels worked offshore, without frequenting arctic ports. The ECAREG data have been supplemented with data extracted from the ***Hudson*** and ***Baffin*** log books concerning the positions of those vessels.

Information about commercial shipping off Greenland's west coast was provided by KNI-Greenland Trade, of Aalborg, Denmark, which has a monopoly on commercial shipping in Greenland waters. This information included a general description of commercial shipping patterns at different latitudes along the W Greenland coast. Schedules for passenger and cargo vessels for the 1989 shipping season were also provided. Data for the Greenland portion of the DSS range are based on an analysis of these shipping schedules. These schedules were examined to determine the approximate number of days that commercial vessels were in the DSS range in each of the five seasons. Although these 1989 data do not directly correspond to any of the years in the 1974-1986 study period, they do provide a general indication of commercial shipping levels in W Greenland waters.

Information about exploration wells drilled in Canadian portions of the DSS range was provided by P. Simard, of the Canada Oil and Gas Lands Administration (COGLA) in Ottawa. Information about offshore drilling in W Greenland waters within the DSS range was provided by the Ministry for Greenland (1977). These sources enabled us to determine the number of days per year that drilling was conducted in regions and seasons when DSS bowheads were likely present.

BBS

Industrial activities in the Canadian Beaufort Sea have been compiled, analyzed and mapped in a number of recent studies (Richardson *et al.* 1985a, 1987a; Norton and McDonald 1986; Norton *et al.* 1987), The results of these studies have been summarized by Brouwer *et al.* (1988). Data are available for the years 1980-1986 and are most complete for the 1 August-10 September period. However, data exist for earlier and later periods in some years. Vessel movements were assessed in each of the seven years during the 1980-1986 period. Most of the vessel traffic recorded in these studies was associated with petroleum exploration, although some of the traffic recorded represented 'sea lift' or re-supply operations in support of small communities and Distant Early Warning (DEW) sites. Information on movements by dredges, icebreakers, tugs, barges, drillships and support vessels was included in the compilation. Local vessel traffic around offshore sites, and movements by seismic, sounding and research vessels, were not included in this assessment of vessel activity. (Traffic by seismic and sounding vessels is considered earlier in this report, see 'Marine Seismic Activity '.)

The numbers of trips between specific locations were tabulated by 10-day period. For most years data *were* available *only* for the 1 August-10 September period, To extrapolate these data to the 1 August-15 September 'late summer' season, we generally added the figures for August to 1½ times the 1-10 September figures. For 1985 and 1986, when data for the 11-20 September period were available, we added half of *that* value to the figures for the 1 August-10 September period. Vessel trips for June were presented for the whole month rather than by 10-day intervals. To determine the number of vessel trips in the early summer periods we added half of the June figures to the July figures.

The vessel traffic compilation by Brouwer *et al.* (1988) does not specifically include vessel traffic in the Amundsen Gulf region. However, vessel movements in Amundsen Gulf that originated or terminated in the Canadian Beaufort Sea are included in their data compilation. This probably includes most of the commercial vessel traffic in Amundsen Gulf because most of the vessels transiting Amundsen Gulf are resupply vessels based out of Tuktoyaktuk. These vessels supply the three villages (Sachs Harbour, Holman, and Paulatuk) and two DEW sites (Cape Parry and Clinton Point) bordering the portion of Amundsen Gulf that bowheads occupy. Vessel movements that both originate and terminate in Amundsen Gulf (e.g., a trip from Cape Parry to Clinton Point) would be excluded from the Brouwer *et al. (1988)* database. In order to correct (roughl y) for such unreported legs of trips, we doubled the number of Amundsen Gulf trips reported by Brouwer et *al.* (1988),

Other sources were used in addition to the data from Brouwer *et al.* (1988). Hazard and Cubbage (1982) reported the Amundsen Gulf itineraries of two commercial vessels in late July and August 1979. We have included their observations in the results. Their figures should be regarded as minima, because it was not the intention of Hazard and Cubbage (1982) to report all vessel traffic in Amundsen Gulf in that year.

We examined a number of reports describing research activities related to offshore oil exploration projects in the Alaskan Beaufort Sea, including Gallaway (1983), Davis *et al. (1985)*, Johnson *et al.* (1986), Ljungblad *et al. (1986)*, McLaren *et al.* (1986), and Davis (1987). These reports provided at least general indications of the level of vessel activity associated with those projects.

We were unable to obtain information from the U.S. Coast Guard about Coast Guard icebreaker activities in the BBS range. Some information about the U. S.C.G. *Polar Sea's* activities in the BBS's Bering Sea winter range was reported by Brueggeman *et* al. (1987). Griffiths et *al.* (1987) reported on research activities conducted from the U. S.C.G. *Polar Star* in the BBS's autumn range.

Information about Alaskan Sealift and fuel barge operations was obtained from Chris Herlugson of BP Exploration (Alaska), Anchorage, and Dick Bebo of Crowley Equipment, Anchorage. All of these operations were conducted during the late summer season when the majority of the BBS is east of Alaskan waters. For this reason, Alaskan Sealift and fuel barging operations are not discussed in the Results section.

We examined published accounts summarizing annual shipping activities along the Soviet Union's Northern Sea Route for years 1976-1984 (Armstrong 1977, 1978, 1984, 1985; Anon. 1979, 1980, 1981, 1982, 1983; Barr and Wilson 1985) and a general account of Soviet marine transport capabilities in arctic waters (Armstrong 1979). These reports generally indicated first dates of arrival and last dates of departure from various ports in the Soviet part of the BBS range, and, in addition, gave some indication of the volume of ship traffic passing through the BBS range,

Results

In the following section we discuss all types of commercial vessel operations that have not already been discussed. For the DSS, data on commercial shipping and offshore oil exploration are presented separately. However, because the most complete source of information for the BBS (Brou wer *et al.* 1988) combines these types of vessel activities in its database. the presentation of BBS data combines the vessel traffic data related to commercial shipping and offshore oil exploration. In the comparison of DSS and BBS vessel traffic, we compare the combined commercial vessel and offshore oil exploration traffic in the two regions.

DSS

Commercial Shipping. --Winter. DSS bowheads were assumed to be in Hudson and Davis Straits in winter. The southern limit of the Davis Strait range was assumed to be a line between the northern tip of Labrador and the coast of West Greenland at 65"30'N. No vessel traffic was reported in the Canadian portion of the DSS range during the winter season. However, some limited vessel traffic does occur off West Greenland in winter.

Commercial shipping off the W Greenland coast in winter is restricted to areas south of 67"N latitude. Thus, commercial vessel traffic in the winter range of the DSS is restricted to about 1%0 of latitude (167 km) along the W Greenland coast. Holsteinsborg is the only important settlement along this portion of the W Greenland coast and it represents the northern limit of shipping during the winter season, According to the 1989 shipping schedules, only a single return passage of a passenger vessel to Holsteinsborg was scheduled during that winter season. This passage represented two vessel-days in the DSS range (Table 22). No cargo vessels were scheduled to enter the DSS winter range.

The U.S. Coast Guard icebreaker *Northwind* operated in Baffin Bay and Davis Strait for 29 days in the winter of 1976 (Turl 1987). The *Northwind's* activities in the DSS range represent about two vessel-days per year when averaged over our 13 year study period.

Spring. The spring (April to mid June) range of the DSS includes all of the winter range (Hudson and Davis Straits) plus Baffin Bay and eastern Lancaster Sound. Vessels were reported in the Canadian part of the spring range of the DSS in only two of the seven years for which data were available (Table 22), Two vessels were recorded in the spring range of the DSS in 1984 and 1986. These vessels were in the DSS spring range for 14 days in 1984 and 24 days in 1986.

In spring, shipping in the Canadian part of the DSS range is severely limited by ice conditions. The MV *Arctic* operated there in the springs of both 1984 and 1986. It was making runs to the Nanisivik mine on northern Baffin Island to pick up cargoes bound for Europe. The

Table 22. Vessel traffic in the DSS range reported by ECAREG for 1980-1986 and in the W Greenland shipping schedules for 1989.

	Number of Vessels[1]						Number of Vessel-days[2]					
Year	Winter	Spring	Early Sumner	Late Summer	Autumn	All Seasons	Winter	Spring	Early Summer	Late Summer	Autumn	All Seasons
1980	0	0	3	22	12	25	0	0	28	398	142	568
1981	0	0	3	21	12	23	0	0	55	391	138	584
1982	0	0	4	18	9	21	0	0	45	252	137	434
1983	0	0	3	24	15	26	0	0	49	405	145	599
1984	0	2	5	19	12	22	0	14	61	268	140	483
1985	0	0	4	27	13	28	0	0	29	359	142	530
1986	0	2	3	23	19	29	0	24	68	395	159	646
1980-1986 mean	0	0.6	3.6	22.0	13.1	24.9	0	5.4	47.9	352.6	143.3	549.1
1989 Greenland	1	10	2	3	3	12	2	120	6	11	7	246
Total	1.0	10.6	5.6	25.0	16.1	36.9	2	125.4	53.9	363.6	150.3	695.1

[1] Includes some unreported *Hudson* and *Baffin cruises, see* Methods.

MV *Arctic* is an ice-strengthened bulk cargo carrier, specially designed to operate in arctic waters. Even so, it required the assistance of the Canadian Coast Guard icebreakers *Louis St. Laurent (1984)* or *Des Groseilliers (1986)* to make the trip to Nanisivik so early in the year.

During the spring season both passenger and cargo vessels ply the waters of W Greenland. Three passenger vessels were scheduled to spend ≈62 vessel-days and seven different cargo carriers were scheduled to spend ≈58 vessel-days in nearshore waters of W Greenland in the DSS range. In total these 10 vessels were scheduled to spend 120 vessel-days in the spring range of the DSS, and to travel as far north as the Upernavik district (≈73°N).

Early Summer. Vessels in Canadian waters of Baffin Bay north of 68°N and west through the high arctic islands to 100"W were considered to be in the summer range of the DSS. The southern limit of the summer DSS range in Prince Regent Inlet and Peel Sound was assumed to be 70°N.

Vessels were reported in the early summer (mid June-July) range of the DSS in each of the years from 1980 to 1986. The number of these vessels ranged from three in several years to five in 1984 (Table 22). The number of vessel-days ranged from 28 in 1980 to 68 in 1986. Overall, the average number of days per vessel was 13.4. More than half (199 of 335) of the vessel-days in the Canadian DSS range during this season represented Canadian Coast Guard icebreakers. The other vessels present in early summer were merchant vessels. The 335 vessel-days reported during the seven early summer seasons represent only 9% (335 of 3,844) of the annual vessel traffic in the Canadian DSS range recorded by ECAREG. There was an average of 48 vessel-days/year in the early summer period.

We assumed that the range of the DSS in Greenland waters in summer was restricted to the Thule District. The only settlements in this district are Thule and the Thule Air Base. During the early summer season two cargo ships travelled to the Thule district for a total of ≈6 vessel-days in those Greenland waters likely to be occupied by bowheads (Table 22). Additional vessels may have entered DSS waters to resupply Thule Air Base from U.S. ports.

Late Summer. The late summer (August-mid September) distribution of bowheads was assumed to be the same as the early summer distribution. The number of vessels reported in the late summer range of the DSS in Canada varied from 18 in 1982 to 27 in 1985 and averaged 22.0 (Table 22). The number of vessel days ranged from 252 in 1982 to 405 in 1983 and averaged 353. This is the peak shipping season in the Canadian DSS range, with 64% of the recorded vessel traffic (1980-86) occurring during this season (2,468 of 3,844 vessel-days). Coast Guard vessels accounted for an average of 33% (805 of 2,468) of the vessel-days during this season, This percentage varied from 21% in 1984 to 48% in 1981. The remaining vessel traffic consisted of general merchant vessels on community re-supply missions, vessels conducting scientific research, and cruise ships.

In the late summer season one passenger ship and two cargo vessels were scheduled to spend 11 vessel-days in N Greenland waters (Table 22).

Autumn. The Canadian portion of the autumn range of the DSS includes all of the early and late summer range. After 30 September this range expands southward to include the Canadian side of Davis Strait north of a line between the SE tip of the Meta Incognita Peninsula (≈62°N, 66°W) and the West Greenland coast at 65"30'N. We also assumed that, after 31 October, bowheads would be south of 72*N in Canadian portions of the DSS range, For example, an icebreaker moving south from Lancaster Sound in mid November would not be considered a source of disturbance to DSS bowheads until it began to travel through Canadian waters south of 72"N later in the autumn. The Greenland portion of the DS S range included W. Greenland waters north of 73° (Upernavik district).

The number of vessels reported in the Canadian part of the DSS's autumn range ranged from 9 in 1982 to 19 in 1986, with an average over the seven year period of 13.1 (Table 21). The number of reported vessel-days averaged 143 per year, and ranged from 137 in 1982 to 159 in 1986. Overall, the 1,003 vessel-days recorded in autumn represented 26% (1,003 of 3,844) of the vessel-days reported by ECAREG in the DSS range. Coast Guard icebreakers accounted for 39% of these vessel-days. Among years this percentage varied considerably, ranging from 24% (34 of 142) in 1985 to 54% (74 of 138) in 1981. The rest of the vessels in the autumn range of the DSS were general merchant and research vessels.

In Greenland portions of the autumn range, one passenger ship was scheduled to spend ≈5 vessel-days and two cargo vessels were scheduled to spend 2 vessel-days. Thus, 3 commercial shipping vessels were scheduled to spend ≈7 vessel-days in the Greenland range of the DSS during autumn (Table 22).

Summary. Very low levels of commercial shipping (1 ship, 2 vessel-days) occur within the winter range of the DSS (Table 22). Low levels of commercial shipping occur in spring, early summer, and autumn. Relatively high levels occur in late summer when ≈25 vessels spend more than 350 vessel-days in the DSS range. Overall, 37 vessels spent about 695 vessel-days per year in the DSS range.

Offshore Drilling. --Three exploration wells were drilled in Canadian waters of Davis" Strait during the 1974-86 period (Table 23). Most of the drilling occurred during the early and late summer periods, when bowheads were well north of Davis Strait. Although all of the drilling periods did extend into the early autumn season, all of the drillsites were south of the DSS's autumn range.

Five exploration wells were drilled off W Greenland in 1976 and 1977 (Table 23). Four of the wells were operated entirely within the earl y and late summer periods of 1977. All of these wells were located south of the DSS's summer range. The Kangamiut well was spudded on 4 June 1976. Thus, this well-site was active during 12 days of the spring season when DSS bowheads are sometimes present. This well was drilled by the dynamically-positioned drillship *Pelican* which cannot operate in ice. Thus, the pack ice, and bowheads, had obviously receded northward from the site. It can be concluded that all of the Greenland wells were drilled south of occupied DSS range.

BBS

Winter. --The U.S. Coast Guard icebreaking vessel *Polar Sea* operated in the BBS's Bering Sea winter range in 1979 and 1983. This vessel spent 29 days in the BBS winter range in 1979 and 28 *days* in 1983. Our information about U.S. Coast Guard vessels in the BBS range is incomplete. The *Polar Sea's* activities in the BBS winter range came to our attention because they were reported by Brueggeman *et al.* (1987). It is possible that U. S.C.G. vessels have spent more time in the BBS range in winter and/or other seasons. The *Polar Sea's* operations in 1979 and 1983, averaged over the 13 year study period, are the equivalent of 4.4 vessel-days per year in the winter season.

Table 23. Details of offshore exploratory wells drilled in western Davis Strait, 1979-1982, and in eastern Davis Strait, 1976-1977.

Well Name	Year	Operator	Lat.	Long.	Water Depth (m)	Drilling Unit	Spud Date	Rig Release
Western Davis Strait[1]								
Gjoa G-37	1979	Esso *et al.*	62°56'N	59°07'W	360	Sedco 709	11 July	25 Sept
Hekja 0-71	1979	Aquitaine *et al.*	62°11'N	62°59'W	904	Ben Ocean Lancer	5 July	5 Ott
"	1980	"	"	"	"	ODECO	21 June	13 Ott
Ralegh N-18	1982	Canterra *et al.*	62°18'N	62°33'W	350	Petrel	1 Aug	4 Ott
Eastern Davis Strait[2]								
Kangamiut 1	1976	Total	66°09'N	56°11'W	180	Pelican	4 June	25 Aug
Hellefisk 1	1977	Arco	67°53'N	56°44'w	163	Sedco 445	21 June	8 Sept
Nukik 1	1977	Mobil	65°32'N	54”46'w	104	Sedco 709	2 July	7 Aug
Ikermiut 1	1977	Chevron	66°56'N	56°25'W	447	Pelerin	12 July	14 Sept
Nukik 2	1977	Mobil	65°38'N	54”46'W	117	Sedco 709	8 Aug	5 Sept

[1] From information supplied by P. Simard, Canada Oil and Gas Lands Administration.
[2] From the Ministry for Greenland (1977).

Prior to 1983 there appears to have been little or no winter shipping activity in Soviet waters of the BBS range. Ships based in Pacific ports did not arrive at Gulf of Anadyr ports until early-to-late May in the years 1979-1982 (Anon. 1980, 1981, 1982, 1983). However, in 1983, Soviet shipping authorities determined that the south coast of the Chukchi Peninsula was to be kept open for year-round navigation. The icebreaker *Admiral Makarov* escorted a freighter to the port of Providenya in late February 1983, and in 1984 vessels arrived there in January (Armstrong 1984). If winter shipping in the Gulf of Anadyr continued through 1986 as seems likely, then winter shipping in Soviet BBS waters occurred in 4 of 13 of the years 1974-1986. Assuming that two Soviet vessels each spent five days in BBS waters in each of the years 1983-1986, then eight Soviet vessels spent 40 days in the BBS range. Averaged over the 1974-1986 study period these vessel movements represent 0.6 vessels per year and 3.1 vessel-days per year. If we add those to the minimum figures based on U.S. icebreaker traffic, the minimum winter totals for the BBS range are 0.8 vessels and 7.5 vessel-days per year.

Spring. --The U.S. Coast Guard icebreaking vessel *Polar Sea* spent 15 days in the BBS spring range in 1979. As noted above, the 15 vessel-days should be regarded as a minimum. Averaged over the 13- year study period, this represents 1.2 vessel-days/year in the BBS sPring range.

In the 1970's and early 1980's Soviet vessels based at Pacific ports typically first arrived at Gulf of Anadyr ports in May, presumably after most BBS bowheads had left that area. Soviet vessels usually did not venture into the Chukchi Sea until late June. Thus, there was limited potential for bowheads to be disturbed by spring Soviet shipping in those years, " In 1983-1986, years with the potential for earlier vessel arrivals in the Gulf of Anadyr (e.g., April), there was considerable potential for bowheads still in their Soviet wintering areas to be disturbed by Soviet vessel traffic in spring. Assuming that two Soviet vessels each spent five days in the BBS spring range in April of each of the years 1983-1986, then eight Soviet vessels spent 40 vessel-days in the BBS range. Averaged over the 1974-1986 study period these vessel movements represent 0.6 vessels and 3.1 vessel-days per year. Adding these figures to the minimum figures obtained for U.S. Coast Guard icebreakers results in minimum totals of 0.7 vessels and 4.2 vessel-days per year.

Early Summer---Data for the Canadian Beaufort Sea were available for part (22-31 July) of the 1981 season and all of the 1985 and 1986 seasons (Table 24). The numbers of vessel trips were similar in 1985 and 1986 with 258 and 261 trips respective y. The 177 vessel trips recorded during the 22-31 July period of 1981 is roughly comparable to the 97 and 155 vessel trips recorded during the same period in 1985 and 1986. In 1985, 33 vessels were operating in the BBS early summer range, compared to 24 in 1986. The consistence y of the numbers for the three years with data suggests that 150-275 trips probably occurred in the early summer of each of the years 1979-1986. Most of these vessel trips were associated with offshore oil exploration,

Vessel traffic in Amundsen Gulf appears to be quite limited during the early summer period, when the largest numbers of bowheads are found there. Norton and McDonald (1986) recorded no vessel movements into Amundsen Gulf from the Canadian Beaufort Sea in June and July of 1985 (Table 24). Norton *et al.* (1987) recorded three (= 6) vessel trips in or out of Amundsen Gulf in the early summer period of 1986. All of these trips were during the 22-31 July period. Hazard and Cubbage (1982) reported four vessel trips in late July 1979. These trips were Tuktoyaktuk-Sachs Harbour-Tuktoyaktuk, and Tuktoyaktuk-Cape Parry-Clinton Point. Thus, based on the information available for years ranging from 1979 to 1986, vessel traffic in Amundsen Gulf during the early summer months ranged from zero (1985) to six (1986) vessel trips.

Table 24. Estimated number of vessel trips in the Canadian Beaufort Sea and Amundsen Gulf, 1979-1986. ‘-’ means no data,

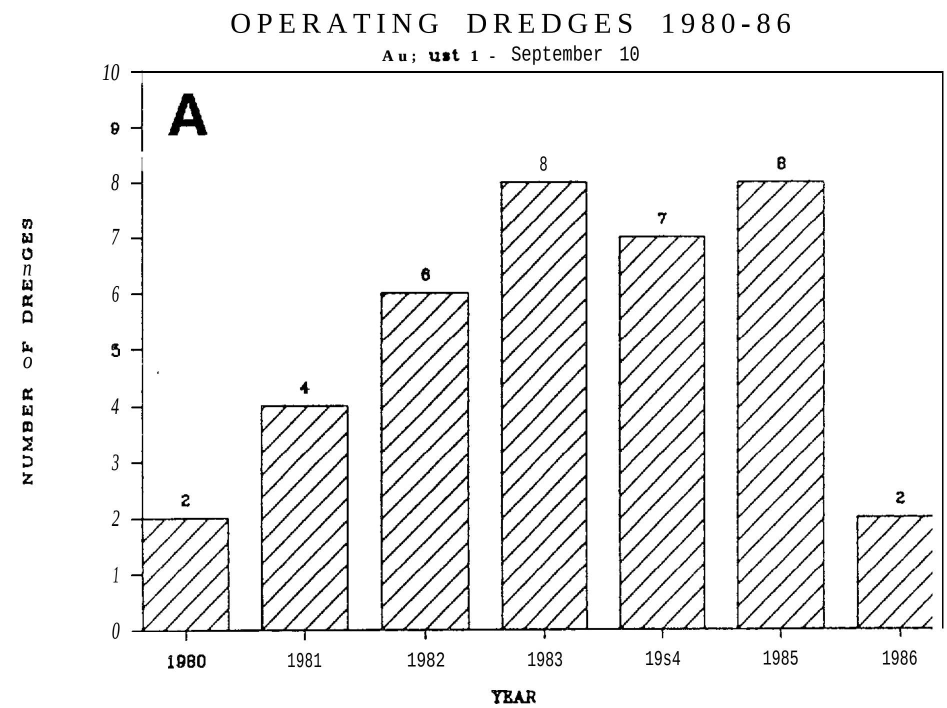
	Early Summer		Late Summer		Autumn	
Year	Canadian Beaufort	Amundsen Gulf[2]	Canadian Beaufort	Amundsen Gulf’	Canadian Beaufort	Amundsen Gulf’
1979		*2*[3]	-	*5*[3]	-	-
1980			599			
1981	177[4]		1044			
1982			960			
1983			1676			
1984		-	1564			
1985	258	0	1246	48[2]	*744*	*2*[2]
1986	261	6[2]	516	50[2]	*134*	*28*[2]

‘16 September-15 October period only.
[2] 1985 and 1986 figures shown have been doubled to correct for the possibility y of unreported trips that were wholly within Amundsen Gulf (see text).
[3] Figures shown are minima as all vessel trips may not have been recorded.
[4] 22-31 July period only.

Late Summer. --The number of vessel trips recorded during the late summer period in the Canadian Beaufort Sea ranged from 516 in 1986 to 1,676 in 1983 and averaged 1,086 over the seven year period (Table 24). In general the number of vessel trips increased after 1980, reached a peak in 1983, and declined thereafter. The number of vessel movements in 1983 was about three times higher than the number recorded in 1986,

Brouwer et *al. (1988)* also reported the numbers of dredges and drill ships that were operating during the late summer periods in each of the years 1980-86. The number of operating dredges ranged from two in 1980 and 1986 to peaks of eight in 1983 and 1985, averaging 5.3 over the seven year period (Fig. 11). The number of operating drill ships was four during the 1980-82 period, five in the years 1983-85, and only two in 1986, averaging 4.1 over the seven year period (Fig. 11). These figures indicate a pattern similar to that observed for numbers of vessel trips--a relatively low number in 1980, increasing to a peak in the mid 1980’s and declining thereafter.

Total or minimum numbers of vessels operating in the Canadian Beaufort Sea were determined for the late summer period for a few of the years examined by Brouwer *et al.* (1988). In 1981 three oil companies operated offshore: Dome Petroleum Ltd. (now Amoco Canada), Esso Resources Canada Ltd., and Gulf Canada Resources Ltd. Dome and Esso alone operated 35 vessels in the area (Richardson cd., 1982). In 1985, about 62 vessels operated in the area, and in 1986 about 40 vessels operated in the area. Considering that 1985 (with about 62 vessels) was not a peak year in terms of numbers of vessel trips, it seems likely that in some years (e.g., 1983 and 1984) considerably more than 62 vessels were present.



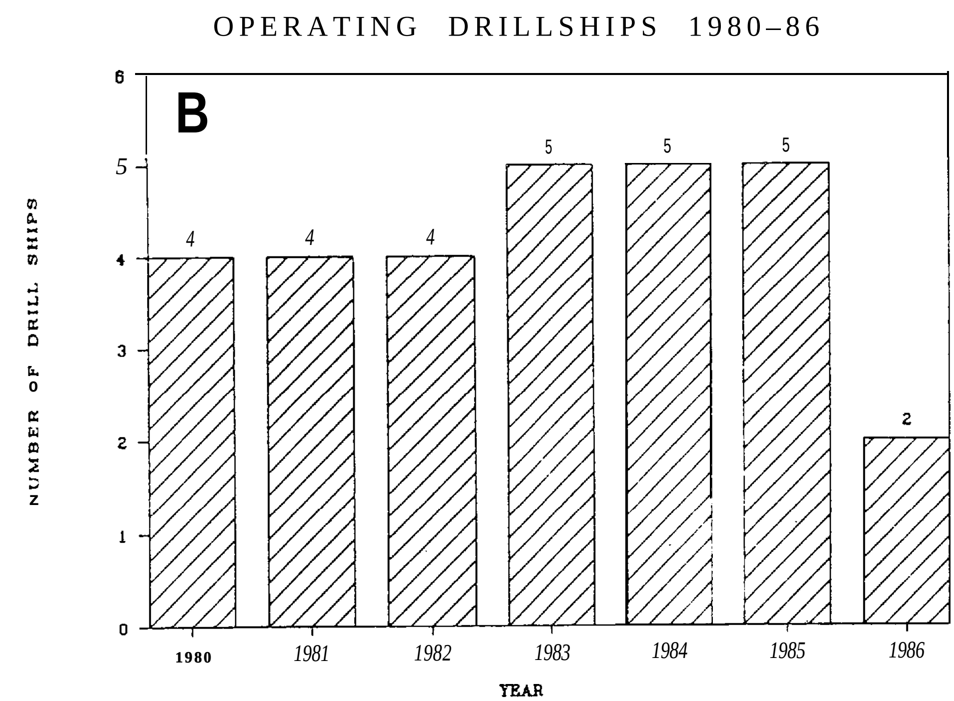


Figure 11. Numbers of operating dredges (A) and drillships (B) during late summer in the BBS range, 1980-86. (From Brouwer et *al.* 1988.)

Vessel activities in Amundsen Gulf during the late summer period are at least an order of magnitude less than those recorded in the Canadian Beaufort Sea. In 1985, Norton and McDonald (1986) recorded 24 (= 48) late summer vessel movements in/out of Amundsen Gulf. In 1986 Norton *et al.* (1987) recorded 25 (= 50) such movements. These low levels of vessel traffic during the peak shipping season seem consistent with some other sources of information. A recent socioeconomic report on the Beaufort Sea region indicated that the communities of Sachs Harbour, Holman and Paulatuk are each supplied by only one barge convoy per year (N.W.T. 1988).

Autumn. --Data for the 16 September-15 October period in the Canadian Beaufort Sea are available for 1985 and 1986 (Table 24). The numbers of vessel trips recorded in the Canadian Beaufort during those years were 134 in 1986 and 744 in 1985, for an average of 439 in the two years. The former year (1986) marked the start of the downturn in drilling in the Canadian Beaufort Sea. Thus, the average, including earlier years, probably exceeded 439 trips/autumn. Most bowheads have left Amundsen Gulf by mid September and vessel traffic in Amundsen Gulf during autumn is very light. Only one (2) vessel movement into and out of Amundsen Gulf was recorded in the autumn of 1985 and 14 (28) were recorded in 1986 (Norton and McDonald 1986; Norton *et* al. 1987). The number of commercial vessels operating in the Canadian Beaufort Sea and Amundsen Gulf in autumn was about 43 in 1985 and 18 in 1986.

Additional autumn vessel activities occurred in the Alaskan Beaufort Sea. Oil exploration began expanding seaward into the Alaskan Beaufort Sea in the early 1980's with the construction of artificial drilling islands. Some of these artificial islands were constructed near the southern edge of the autumn migration route of the BBS. In recent years, oil exploration activities have moved further offshore into deeper waters with the use of a variety of drillships and drilling platforms. Exploration activities (aside from seismic) that had the potential to influence bowhead whales during autumn migration through the Beaufort Sea are listed in Table 25.

Oil leases issued for the Alaskan Beaufort Sea have included stipulations designed to protect bowheads. The details of these stipulations have varied among lease sales and locations. However, in most cases the intent has been to prohibit or restrict drilling at times when bowheads are likely to be migrating near drillsites, or when the autumn bowhead hunt is in progress. In the following section autumn offshore exploration activities in the Alaskan Beaufort Sea are examined on a year-by-year basis.

Although offshore drilling has been restricted during autumn migration in most years, non-drilling activities associated with offshore petroleum exploration often continue, and these activities have the potential to disturb BBS bowheads. Seal Island was still under construction in the fall of 1982. Construction activities during this period have been described by Gallaway (cd., 1983). These included the bagging of gravel in 3.3 m^3 bags and placing the bags on the island slopes to prevent erosion from wave action. This operation involved the use of three front-end loaders, a large crane on tracks, a bulldozer and a motor-driven bagging plant. Barge traffic to and from the island was heavy during open water periods with low sea states. A Bell 212 helicopter was used for crew changes; it travelled to and from Prudhoe Bay twice a day and there were other intermittent helicopter flights to and from the island during the day. Construction activities ceased by 4 October, having occurred on about 18 days of the autumn season.

By the autumn of 1984, the construction of Seal Island was complete (Davis et *al.* 1985). Drilling had already begun, but ceased by mid September. Well-logging was conducted until 20 September and routine maintenance was carried out through the autumn period. There was also helicopter and barge traffic to and from the island.

Table 25. Autumn offshore oil exploration activities during fall bowhead migration through the Alaskan Beaufort Sea, 1974-86.

Year	Site	Location		Platform	Water Depth (m)	Activities
1982	Seal Island	70°29.5'N	148°42'W	Artificial Island	12	Island construction, bagging plant operation, bag installation
1984	Seal Island	70°29.5'N	148 °42'W	Artificial Island	12	Well-1ogging, island and equipment maintenance
1985	Sandpiper Island	70°35.1'N	149°06' W	Artificial Island	15	Limited well drilling (after 11 October)
	Hammerhead	70°21.6'N	146°21 'W	Drillship	32	Well-testing
	Corona	70°18.9'N	144°50'W	Drillship	35	Standing by
	Orion Prospect	70 °57.2'N	152°04'W	CIDS*	15	Support activity
	Erik Prospect	70°20.7'N	143°59'W	Drillship	40	Limited drilling
1986	Hammerhead	70"22.3'N	146°00'W	Drillship	34	Well drilling
	Corona	70°18.9'N	144°45' W	Drillship	35	Well drilling

* Concrete Island Drilling Structure.

Drilling at Sandpiper Island in 1985 was not authorized while the autumn bowhead hunt was underway (Johnson *et al.* 1986). No drilling occurred from 4 September-11 October. Drilling activities resumed on 12 October, and continued for about eight days of the autumn migration, which officially ended on 20 October in that area.

In the summer of 1985 the ice-strengthened drillship *Canmar Explorer II* drilled an exploratory well at the Hammerhead prospect north of Flaxman Island. The Hammerhead well was in deeper water (32 m) than the aforementioned islands, and was the first well to be drilled by a drill ship in the Alaskan Beaufort Sea (McLaren *et al.* 1986). Support vessels included a Class 3 icebreaker and two icebreaking supply ships. The drillship was visited daily by helicopters and frequently by supply barges from Prudhoe Bay. Drilling ceased before the autumn bowhead migration began, but the drill ship and support vessels continued well-testing at Hammerhead during the early portion of the 1985 migration. The drillship and support vessels stood by at or near the Corona prospect, another drillsite farther east in Camden Bay, during later periods of the 1985 migration.

The CIDS (concrete island drilling structure) was at the Orion Prospect in Harrison Bay when the autumn season began. Drilling did not begin until November, after the autumn bowhead migration, but support activity (presumably by supply vessels and helicopters) carried on throughout the bowhead migration (Ljungblad et *al.* 1986). There was also activity at the Erik Prospect near Kaktovik in October. Some drilling (type unspecified) was conducted at that site by the *Canmar Explorer II* (Ljungblad *et al.* 1986).

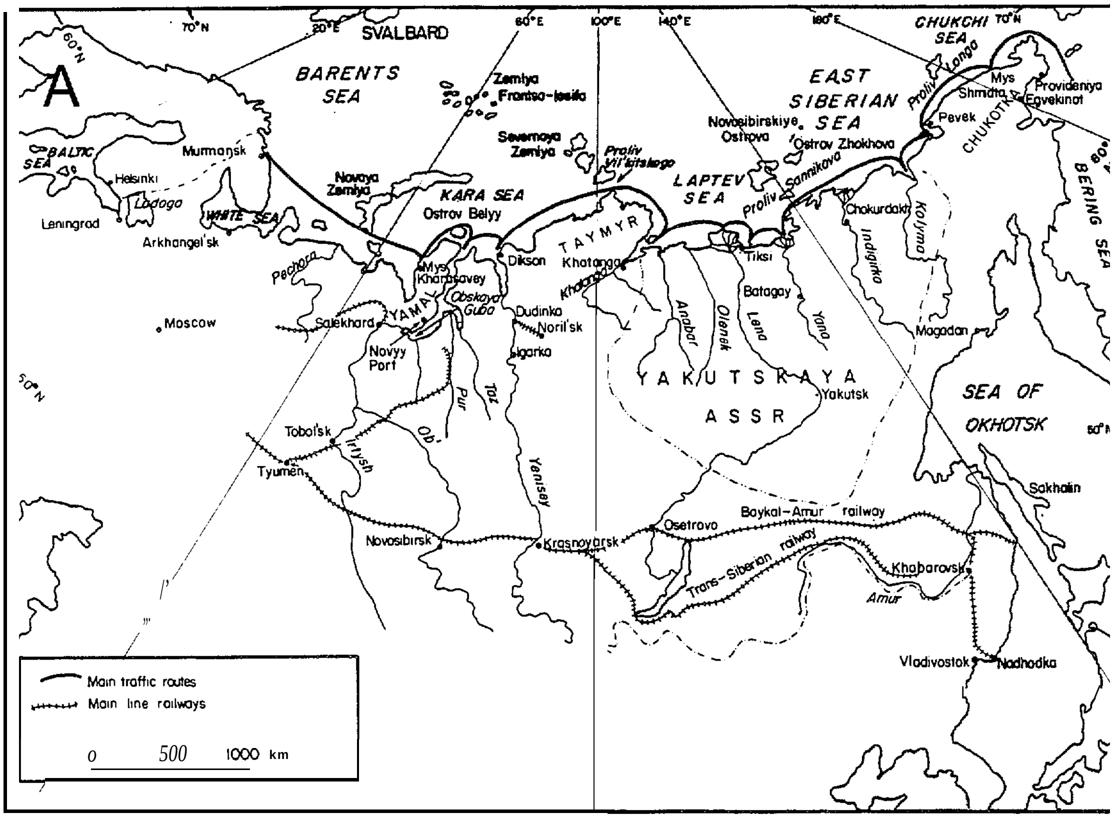
In 1986, the *Canmar Explorer II* was again operating on the Corona and Hammerhead prospects. The drillship was supported by two full-time icebreaking supply ships and a Class 3 icebreaker (Davis 1987). At various times, additional support was also provided by another Class 3 icebreaker, another supply ship, and a tug and assorted barges, The drillship was also serviced by twin-engined turbine helicopters from Prudhoe Bay. Drilling began in July at the Corona site and continued until 17 September. The drillship moved to the Hammerhead site on 18 September, where it drilled until 10 October. Thus, the *Explorer II* conducted drilling activities for about 25 days during the autumn migration,

Biological research has been conducted from vessels in the BBS's Alaskan range in some years. Griffiths *et al. (1987)* reported on studies conducted in Alaskan Beaufort Sea waters from the U. S.C.G. *Polar Star (14* days in October 1986) and the *Annika Marie (5* days in late September during each of 1985 and 1986).

Large-scale commercial shipping operations are conducted in the Soviet Arctic in autumn. The Soviet Union has the largest and most powerful fleet of icebreakers in the world. In 1977, 30 icebreakers and 257 self-propelled ships of over 100 tons on the Soviet register were cleared for sailing on the Northern Sea Route (Armstrong 1979). The major port near the autumn BBS range is Pevek on the north coast of the Chukchi Peninsula (Fig. 12). In 1982 this port handled 200 ships in the 3½ month shipping season. Some of these vessels would have been based in the west (Murmansk), and therefore would not have had the potential to disturb BBS bowheads on either leg of their return trip. However, most would have arrived from and departed for ports in the Pacific Ocean, especially Vladivostok, and would have had the potential to disturb BBS bowheads in autumn. One Pacific-based tanker made three return voyages to the Soviet arctic in 1982 (Anon. 1983).

It is not possible to determine precisely how many of the vessels operating in the eastern sector of the Northern Sea Route had the potential to disturb BBS bowheads in autumn. However, some indications of the volume of autumn shipping traffic in that region are evident from a description of the calamitous 1983 shipping season (Armstrong 1984; Barr and Wilson 1985). In late September about 70 ships, together with eight icebreakers, were in or near the Port of Pevek. Unusually early ice formation along the northern coast of Chukchi Peninsula caused 51 ships to be caught in the ice in October. With the help of 13 icebreakers all of the vessels except one (which sank) were rescued, some as late as mid November.

The presence of as many as 78 ships along the northern coast of the Chukchi Peninsula in late September suggests that Soviet shipping has considerable potential to disturb BBS bowheads in autumn. If only two-thirds of these vessels originated from Pacific ports, then there was the potential for 52 vessel trips from the northern Chukchi coast through Soviet waters where the BBS bowheads might be expected to be found in autumn. The autumn shipping season in Soviet portions of the BBS range ends in mid October in some years, and as late as mid November in other years. If each of the 52 vessels spent an average of 10 days in the autumn BBS range then these vessels spent 520 vessel-days in the BBS range. Because no other data are available, the 52 vessels and



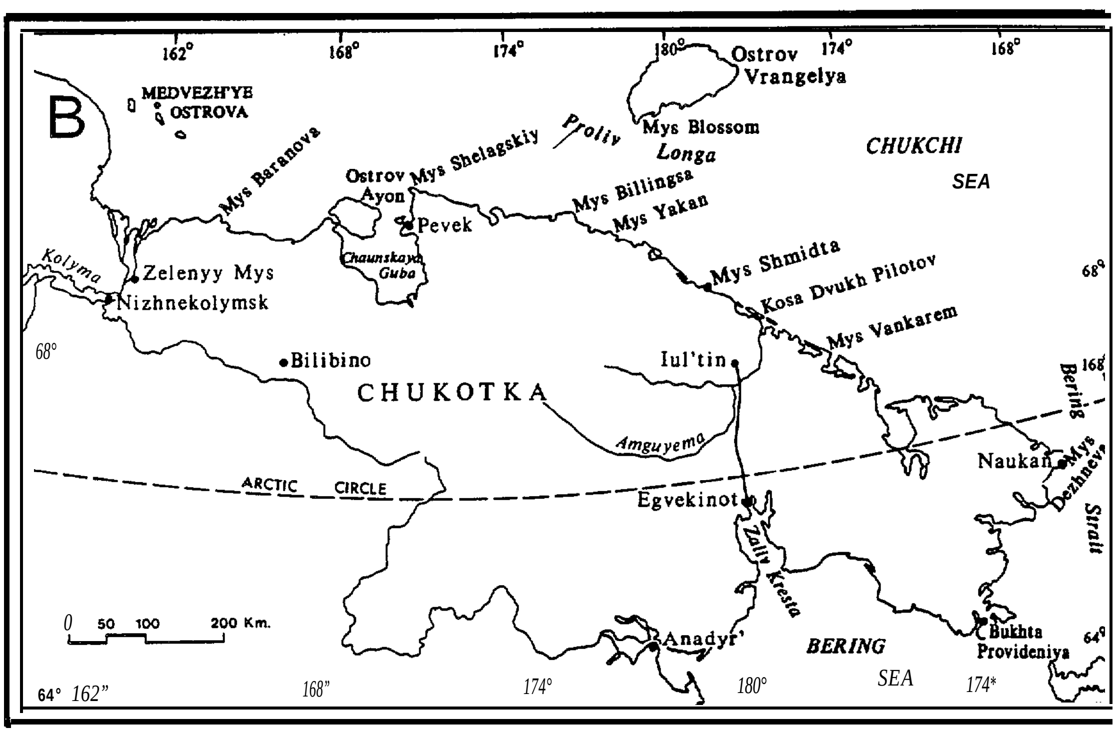


Figure 12, (A) The Soviet Northern Sea Route (from Armstrong 1985). (B) The eastern sector of the Northern Sea Route, showing major Soviet ports in the BBS range (from Barr and Wilson 1985).

520 vessel-days derived from the account of the 1983 season are assumed to represent average levels of autumn shipping activity in Soviet waters for the entire 1974-1986 study period.

Summary .--The greatest amount of vessel traffic in the Canadian Beaufort Sea and Amundsen Gulf occurred during the late summer period. In 1985 and 1986, the only years with complete information for all three open water seasons, the late summer season accounted for 5670 and 57 %, respectively, of the recorded vessel trips (Brouwer et *al.* 1988). Early summer vessel trips represented 1170 and 2770 of the total vessel trips recorded, while autumn trips represented 32% and 16%, The numbers of vessels operating in 1985 and 1986 in the Canadian portion of the BBS range were about 33 and 24 in early summer, 62 and 40 in the late summer, and 43 and 18 in autumn. An estimated 52 vessels operated in Soviet portions of the BBS range in autumn, in addition to as many as seven in Alaskan waters.

Comparison of DSS and BBS Exposures

Winter

In winter, the amounts of commercial shipping in the range of the DSS (1 vessel and 4 vessel-days per year) and BBS (minimum of 0.8 vessels and 7.5 vessel-days per year) appear to be roughly similar. However, information for the BBS is incomplete, and BBS levels may be higher than indicated. Nonetheless, levels in both areas were trivial.

Spring

Levels of commercial shipping in spring appear to be higher in the DSS range than in the BBS range, In the case of the DSS, spring shipping occurs primarily along the W Greenland coast where ice conditions are not as severe as in the Canadian portion of the DSS range, The levels of commercial shipping observed in the DSS range (10.6 vessels and 125.4 vessel-days) can be compared to very limited spring commercial shipping in the BBS range (minimum of 0.7 vessels and 4.2 vessel-days per year). However, as noted above, information about U.S. Coast Guard vessels is incomplete, and BBS spring shipping levels may be slightly higher than indicated.

Early Summer

In the DSS range, commercial shipping involved an average of 5.6 vessels and 53.9 vessel-days per year in early summer. In the BBS range in 1985 and 1986, the numbers of commercial vessels were about five times higher, at 33 and 24 vessels, respectively. Commercial vessel traffic during early summer was clearly more intensive in the range of the BBS than for the DSS, at least in years since 1976 when offshore oil exploration in the Beaufort Sea became significant.

Late Summer

Commercial vessel activity in late summer has been much higher in the range of the BBS than in the range of the DSS. In 1985 and 1986, approximately 62 and 40 commercial vessels, respective y, operated in the BBS range compared to an estimated 25 vessels in the DSS range. The DSS vessels, on average, spent an estimated 14.6 days in the DSS late summer range. In contrast, many of the BBS vessels, especially those associated with offshore petroleum exploration, operated full-time in the BBS range. The open water season in the BBS range is short and exploration companies try to accomplish as much as possible during the brief ice-free season. Some vessels (e. g., drillships, icebreakers, dredges, and supply ships) would have spent nearly all of the 46 late summer days operating in BBS waters.

Autumn

In the range of the DSS, an estimated average of 16.1 vessels spend an estimated 150 vessel-days per autumn season. In the Canadian Beaufort Sea, the average of the numbers of vessels operating in 1985 (43) and 1986 (18) was 30.5. The 1985 estimate of 43 vessels more nearly approximates the activity levels of the early 1980's when exploration levels were high (Table 23). In addition to the higher number of vessels operating in the BBS range in autumn, the number of vessel-days associated with these vessels is likely much higher than the 9.3 vessel-day average associated with DSS vessels in autumn. As well as the commercial vessel activity in the Canadian Beaufort, there has been some oil exploration activity in the Alaskan Beaufort in autumn in recent years. In 1986, for example, at least seven vessels were associated with the drilling activity at the Corona and Hammerhead prospects and two vessels were conducting biological research. In Soviet waters an estimated 52 vessels passed through the autumn range of the BBS. Combining this figure with the average number (30.5) of vessels in the Canadian Beaufort Sea in the autumns of 1985 and 1986 results in a total of 82.5 vessels. This total is more than five times higher than the DSS autumn total, even without including any vessels using Alaskan waters.

Summary

In summary, commercial vessel operations in the range of the BBS have been markedly higher than in the range of the DSS in early summer, late summer and autumn. BBS and DSS commercial shipping levels are approximately equal, and trivial, in winter. Commercial shipping levels in the DSS range appear to have been higher than BBS levels in spring.

An average of 37 different commercial vessels operated in the range of the DSS in 1980-1986 (Table 22). Some of these vessels operated in more than one season. Summing the number of vessels operating in each season results in a total of 58 vessel-seasons. In the Canadian Beaufort Sea, 67 different commercial vessels operated in 1985; the total of 1,246 vessel trips recorded in 1985 was similar to the average of 1,086 vessel trips per year over the 1980-1986 period. Summing the number of vessels operating in each season results in a total of 138 commercial vessel-seasons. Adding 52 vessels for Soviet waters in autumn and five vessels for Alaskan waters in autumn results in a total of 195 vessel-seasons. Thus, more than three times as many commercial vessels were operating in the range of the BBS. As noted earlier, because of the nature of the offshore oil exploration in which many of the BBS vessels were involved, the number of vessel-days associated with these vessels may have been much higher than for typical vessels in the range of the DSS.

Low-Level Aircraft Flights

Low-flying aircraft have the potential to disturb DSS and BBS bowheads. In this section we assess types of aircraft operations that may include low level (here defined as <1,000 ft ASL) flights with the potential to disturb bowheads. Flights that are conducted for the most part at high altitudes include commercial scheduled flights and some types of ice reconnaissance. These flights reach altitudes <1,000 ft ASL on] y while taking off and landing. When bowheads occur near coastal airstrips there is the potential for bowheads to be disturbed by these flights. Coast Guard icebreakers usually carry a turbine helicopter on board. These helicopters conduct low-level ice reconnaissance near the icebreaker. Helicopters are also used to support offshore drilling operations. Helicopters performing this function are almost always twin-engine turbine models. (Most helicopter operations conducted in support of offshore drilling are flown at altitudes above 1,000 ft.) A final type of low-level aircraft operation consists of biological or oceanographic survey flights, Typically, these flights have used grid patterns of transect lines that are flown regularly by fixed-wing aircraft at low altitudes.

Data Sources

Coastal Airstrips

To assess the potential for low-level aircraft traffic at coastal airstrips, we compiled a list of such airstrips in the DSS and BBS ranges using World Aeronautical Charts as a basic reference. A number of airstrips were excluded from these lists because, although strictly speaking they are coastal, they are at the heads of long inlets, sounds or fiords unlikely to be frequented by bowheads (e.g., Iqaluit and Pangnirtung in the DSS range). Cape Dyer along the E Baffin coast was excluded because its altitude is more than 1,000 ft ASL. After considering seasonal ice conditions and bowhead distribution, we identified the coastal airstrips where the potential exists for bowheads to be disturbed by low-level flights during one or more of the five seasons.

Low-Level Helicopter Flights

ECAREG records were used to determine how many Canadian Coast Guard helicopters were in the DSS range during each year from 1980 to 1986. We assumed that there was a helicopter associated with each of the Canadian Coast Guard icebreakers in the DSS range. For U.S. Coast Guard helicopters in the BBS range, we used the limited information reported by Brueggeman *et al.* (1987) and Griffiths *et al.* (1987). To determine the numbers of helicopters operating in support of offshore oil drilling in the BBS range we used information provided by Brouwer *et al.* (1988). They presented data on the numbers of helicopters operating in the BBS range during the 1 August- 10 September period (which closely corresponds to the late summer season) for the years 1980-1986. For BBS drilling operations that did not specify how many helicopters were employed, we assumed that an average of two helicopters were associated with each offshore well, based on information provided by P. Simard (COGLA) and our experience.

Low-Level Survey Flights

To assess low-level research flights, we began compiling a list of the studies involving low-level aerial components in the DSS and BBS in the years 1974-1986. Because of the number of such studies that have been conducted over these years, we sampled every third year, beginning with 1974. Thus, studies with aerial components conducted in the five years 1974, 1977, 1980, 1983 and 1986 were examined.

Some listed studies utilized survey aircraft for several different purposes, which required flying at different altitudes. For example, Richardson *et al.* (1987b) conducted a study which included low-level aerial photography (≈500 ft), low-level systematic aerial surveys (500 or 1,000 ft), and higher level reconnaissance and behavioral observation flights (1500-2,000 ft). Other studies (e.g., Ljungblad et *al.* 1984a) noted that although their standard survey altitude was 1,000 ft, lower ceilings or other weather conditions sometimes dictated lower survey altitudes. Rather than try to determine how many km of surveys were flown at an altitude of 1,000 ft or less during a given study, we opted to determine how many aircraft were used per season in any study that had aerial survey components that were flown at or below 1,000 ft.

Results

DSS ‘

Coastal Airstrips---During winter in most of the DSS region there are broad bands of fast ice extending from the coast. In areas where this is the *case,* aircraft flying in or out of coastal airstrips would be at altitudes well above 1,000 ft while over the moving pack ice occupied by bowheads. Thus, there is little potential for DSS bowheads to be disturbed by low-level flights during winter. Ice conditions are typically lighter on the eastern side of Davis Strait along the W Greenland coast, however, and portions of the Greenland coast from Holsteinsborg south are often ice free during the winter season. Thus, the airstrip at Holsteinsborg is probably the only one in the DSS range where low-level flights have the potential to disturb bowheads during the winter season (Table 26).

Table 26, Coastal airstrips where arriving and departing aircraft may be below 1000 ft ASL over waters that could be used by DSS bowhead whales.

	Season				
Airstrip	Winter	Spring	*Early* Summer	Late Summer	Autumn
Holsteinsborg	+[1]	+			
Egedesminde		+			
Christianshaab		+			
Jakobshavn		+			
Godhavn		+			
Umanak		+			
Upernavik		+			
Pond Inlet			“4-	-b	+
Clyde				+	-1-
Nanisivik				+	+
Arctic Bay				-1-	+
Resolute				+	
Grise Fiord				+	
Cape Hooper					+
Broughton Island					+

[1] ‘+’ indicates coastal airstrip where potential exists for low-level flights over DSS bowheads.

During the spring, fast ice conditions are similar to those found in winter except for a northward shift in ice-free conditions to waters of W Greenland as far north as the Upernavik district (≈73°N). Thus, additional coastal airstrips where low-level flights have the potential to overfly DSS bowheads during this season include Egedesminde, Christianshaab, Jakobshavn, Godhavn, Umanak, and Upemavik (Table 26).

In early summer (mid June-July) most DSS bowheads occupy the northern Baffin Bay region. Although bowheads enter Lancaster Sound in mid July, beginning their penetration into the various channels, bays and fiords between the Canadian arctic islands, the only airstrip likely to have bowheads in its immediate vicinity during this season is at the village of Pond Inlet (Table 26).

By late summer the fast ice has broken up and bowheads are able to migrate into the important summering areas of Eclipse Sound, Admiralty Inlet, Prince Regent Inlet and Isabella Bay. Airstrips that might have bowheads in the immediate vicinity during the late summer season include Grise Fiord, Resolute, Nanisivik, Arctic Bay, Pond Inlet and Clyde (Table 26).

During the autumn season bowheads migrate east past northern Baffin Island and turn south along the E B affin coast. Coastal airstrips that might have bowheads in their immediate vicinity during this season include Arctic Bay, Nanisivik, Pond Inlet, Clyde, Cape Hooper, and Broughton Island (Table 26).

Although Table 26 lists a fairly large number of airstrips where low-level flights have the potential to disturb bowheads, the actual occurrence of such disturbance is quite limited. First, there is relatively little aircraft traffic in the region. Most of the airstrips serve small villages and are used by only a few flights a week. Only a few of the airstrips (e.g., Resolute and Nanisivik) accommodate large jet aircraft (Boeing 737 's) and more frequent flights. Second, the likelihood of bowheads being near the airstrips is relatively low. The DSS is small in numbers and the population is well dispersed in most seasons. None of the airstrips are in the immediate vicinity of known bowhead concentration areas where large numbers of bowheads are expected. In summary, we suspect that bowhead disturbance from low-level flights near coastal airstrips is an infrequent event in the range of the DSS.

Helicopter Traffic. --Helicopters operate in the DSS range in support of Coast Guard icebreakers and off shore drilling operations, Assuming that there was a helicopter associated with each icebreaker, then there were an average of five (range 4-7) Coast Guard helicopters per year operating in the DSS range. All of these were single-engine helicopters.

Low-Level Survey Flights. --Table 27 lists studies in the DSS region that included low-level aerial survey components in -the years 1974, 1977, 1980, 1983 and 1986. Studies were conducted in all seasons of the year, but most aircraft were used in the early summer season. Overall, there were 20 aircraft-seasons of surveys in 14 seasons of the 25 season 5-year sample (0.8 aircraft/season on average; 1.6 aircraft/early summer).

BBS

Coastal Airstrips---During winter in most of the BBS region there are broad bands of fast ice extending from the coast. For this reason aircraft flying in or out of most coastal airstrips in the BBS's winter range (e.g., Gambell or Savoonga) would be at altitudes >1,000 ft while over open water. The low-level portions of those flights would be over fast ice rather than pack ice or open water. There is limited potential for BBS bowheads to be disturbed by flights into or out of the Soviet airstrip at Urelik (Providenya, Table 28). This is one of only two hard-surfaced runways the Soviet BBS range and at 4,000 ft is one of the longest and probably one of the busiest. The strip is located near the Gulf of Anadyr polynya that some bowheads occupy in winter. However, it is more than 8 km inland from the Anadyr coast and most aircraft approaching or departing over the Gulf presumably would be at altitudes >1,000 ft.

Table 27. Summary of studies involving the use of low–level (≤1000 ft) aircraft flights with the potential to overfly DSS bowheads during selected years from 1974–1986.

Year	No. of Aircraft/Season: Winter	Spring	Early Summer	Late Summer	Autumn	Aircraft Type	Reference
1974		1	1	1		Cessna 337, Twin Otter	Finley *et al.* (1974)
"			1	1		Twin Otter or Bell 206	Smith *et al.* (1985)
1977	1	1				DC-3	MacLaren Atlantic Ltd. (1977a)
"				1	1	Twin Otter	MacLaren Atlantic Ltd. (1977b)
"			1	1		Twin Otter, Cessna 337	Davis *et al.* (1978)
"			1	1		Twin Otter or Bell 206	Smith *et al.* (1985)
1980			1	1		Twin Otter or Bell 206	Smith *et al.* (1985)
1983			1			Bell 206	Finley et al. (1984)
1986		1	1			Bell 206	Cosens and Dueck (1988)
"			1			Twin Otter	Barber and Hochheim (1986)
"					1	Twin Otter	Finley (1987)
Total	1	3	8	6	2		

Table 28. Coastal airstrips where arriving and departing aircraft may be below 1000 ft ASL over waters that could be used by BBS bowhead whales.

Airstrip	Season: Winter	Spring	Early Summer	Late Summer	Autumn
Mys Billingsa					+[1]
Somnitelnaya					+
Mys Shmidta					+
Vankarem					+
Lavrentya		+			+
Urelik (Providenya)	+	+			+
Gambell					+
Savoonga					+
Wainwright		+			
Barrow		++[2]			+
Sachs Harbor			+	+	
Holman			+	+	
Clinton Point				+	
Cape Parry				+	
Nicholson				+	
Shingle Point				++	++
Stokes Point				+	+
Komakuk				++	++
Barter Island					+

[1] '+' indicates coastal airstrip where potential exists for low-level flights to disturb DSS bowheads.
[2] '++' indicates coastal airstrip where relatively greater potential exists for low-level flights to disturb bowheads.

In spring, fast ice conditions are similar to those in winter. Bowheads migrate north through Bering Strait and along a lead that forms along the Chukchi Sea coast of NW Alaska. The southern end of this lead is far offshore, but it closely approaches the coast near Wainwright and Barrow. At Barrow, in particular, there is significant potential for arriving and departing aircraft to fly over BBS bowheads (Table 28). The vast majority of the BBS passes through the nearshore lead at Barrow, and the airport accommodates a relatively large amount of air traffic. In addition to numerous small aircraft, 2-3 Boeing 737's and a C 130 Hercules transport fly in and out of the airport on a daily basis, Most flights approach the airport from over the lead. During the years under consideration, a DEW-line airstrip several miles north of Barrow handled additional aircraft, including the once-weekly arrival and departure of the ' Dewliner' -often an F27. Soviet airstrips at Urelik (Providenya) and Lavrentya may constitute additional sources of disturbance to BBS bowheads migrating along the eastern Chukchi Peninsula coast.

In the early summer period the BBS *is* found primarily in Amundsen Gulf and the eastern Beaufort Sea. The only coastal airstrips in the BBS range during this season are at Sachs Harbor and Holman (Table 28).

During the late summer period, BBS bowheads tend to ‘concentrate in the southeastern Beaufort Sea, but are also found in Amundsen Gulf. During this season, there are *a* number of DEW-line airstrips where bowheads might be exposed to low-level flights (Table 28). Three airstrips (Shingle Point, Stokes Point, and Komakuk) along the Yukon Coast are near areas where large late summer concentrations of bowheads occur in some years. There is a relatively greater potential for bowheads to be disturbed by low-level flights at Shingle Point and Komakuk because these are active DEW-line sites. The Stokes Point site is abandoned, but the airstrip is still used occasionally. On 2 September 1984 a research team taking low-level (475 ft ASL) calibration photographs at the Stokes Point runway repeatedly encountered bowheads immediatel y off the end of the runway (Davis *et al.* 1986a).

By autumn most bowheads have left Amundsen Gulf. Coastal airstrips where the potential exists for bowheads to be disturbed by low-level flights in autumn include some of the same sites listed for the summer season, as well as the Barter Island and Barrow DEW-line sites (Table 28). During September and October bowheads may be exposed to low-level flights near Soviet airstrips (Table 28). Three airstrips (Mys Billingsa, Mys Shmidta and Vankarem) are located along the north coast of the Chukchi Peninsula (Fig. 12). Mys Billings a, and to a lesser extent Mys Shmidta are at the extreme western edge of the BBS range, where bowheads only occasionally are recorded. The Somnitelnaya airstrip is on the south coast of Wrangel Island. In October and November migrating bowheads may also be exposed to low-level aircraft flights near Lavrentya and Urelik (Providenya) along the east and southeast Chukchi Peninsula coasts. Some BBS bowheads reach their Bering Sea wintering grounds by November (Johnson *et. al.* 1981) and have the potential to be overflown by low-level flights arriving at and departing from the coastal airstrips at Gambell and Savoonga.

Helicopter Traffic. --The number of helicopters operating in the BBS range during the 1 August-1 O September ‘core period’ (which closely corresponds to the late summer period) varied from 5 in 1980 to 11 *in* 1985 and totalled 57 (8/year) during the 1980-1986 period (Brouwer *et al.* 1 988). This is clearly a minimum figure for those years because it is based on helicopter traffic in a single season. Although Brouwer *et* al. (1988) do not present data concerning the numbers of helicopters operating in their Canadian Beaufort Sea study area during other seasons, they do present data on the number of helicopter trips for the early summer, core, and autumn periods of 1985 and 1986. The numbers of helicopter trips were lower in the early summer and autumn periods than in the core periods of 1985 and 1986, but remained substantial.

Brueggeman (1987) reported that the U.S. Coast Guard icebreaker *Polar Sea* carried two helicopters in the winter and spring seasons of 1979 and in the winter season of 1983. The U. S.C.G. *Polar Star* carried two helicopters in the autumn of 1986 (D. Thomson, LGL, pers. comm.). As noted previously, our information about U.S. Coast Guard vessels in the BBS range is incomplete and it is possible that additional U. S.C.G. icebreakers (and associated helicopters) were in the BBS range during the study period.

Additional autumn helicopter traffic was associated with offshore drilling operations in the Alaskan Beaufort Sea. If we assume that two helicopters were associated with each of the nine offshore drilling operations described in Table 25, then there were an additional 3-4 helicopters in operation annually from 1982 to 1986. Allowing for these, the icebreakers’ helicopters, and those in the Canadian Beaufort, an average of at least 11 helicopters per year were in use in the range of the BBS. Additional helicopters were associated with Soviet icebreakers operating in the BBS range in autumn (Barr and Wilson 1985).

Low-Level Survey Flights. --Table 29 lists biological and oceanographic studies with low-level aerial survey components conducted in the BBS range in the years 1974, 1977, 1980, 1983 and 1986. Studies were conducted in all seasons of the year, but the most aircraft activity was in the late summer season. In total these research efforts represented 40 aircraft-seasons of surveys in 18 seasons of the 25 season, 5-year sample (1.6 aircraft/season on average; 3.8 aircraft/late summer). Much of this research was directed specifically at bowheads.

Comparison of DSS and BBS Exposures

With regard to the three types of low-level aircraft traffic that we assessed, levels were higher in the BBS range than in the DSS range in all cases. (1) Although there are numerous coastal airstrips in the range of the DSS where bowheads "could potentially have been disturbed by arriving and departing aircraft, the incidence of this type of disturbance is probably quite low in the DSS range. For the BBS significant potential exists for such disturbance at Barrow in spring and at Komakuk and Shingle Point DEW-line sites in late summer and autumn. (2) Levels of helicopter traffic in the DSS range, at 5 operating helicopters per year, are about half the minimum estimate for the BBS region of 11 operating helicopters per year. (3) Low-level research flights probably constitute the most significant source of aircraft disturbance to bowheads. Many of the BBS surveys have been specifically designed to study bowheads and some of these surveys are flown in areas where bowheads are most likely to be found. Here again, activity in the range of the DSS, with ≈ 0.8 aircraft/season, was approximately half that for the BBS region (1.6 aircraft/season). Inclusion of data on Soviet low-level research flights and low-level helicopter flights (had they been available) would have increased the indices of low-level aircraft disturbance for the BBS for the winter, spring and autumn seasons.

OVERALL DISTURBANCE LEVELS

The design of the present study is based on the assumption that bowhead whale populations in two parts of the North American Arctic have been exposed to different levels of human-induced disturbance in the 13 year period from 1974 to 1986. If so, differences in behavior in the two populations might then be attributable to the cumulative effects of these differing levels of disturbance. Thus, it is essential to determine whether there have been substantial differences in the levels of human activity in the two areas,

Previous sections of this report have discussed potential disturbance sources singly. The important question is, however, the overall level of disturbance to which animals in each population are exposed. It is necessary to integrate the data for all of the sources of potential disturbance to determine composite measures of potential disturbance to the DSS and BBS populations. We attempt this integration in this section.

In addition to the quantitative comparisons for each type of human activity, the integration requires that some assessment of the relative importance of each source be made. Also, it is necessary to consider the numbers of animals that are likely to be exposed to the disturbances. For example, not all parts of the occupied range contain the same numbers of bowheads at any one time. Thus, it is important to consider the locations of major concentration areas as well as the

Table 29. Summary of studies involving the use of low-level (<1000 ft) aircraft flights with the potential to overfly BBS bowheads during selected years from 1974-7986.

Year	No. of Aircraft/Season: Winter	Spring	Early Summer	Late Summer	Autumn	Aircraft Type	Reference
1974				1	1	?	Fiscus and Marquette (1975), cited in Braham *et al.* (1984)
1977	1	1		1	1	Goose[1]	Braham *et al.* (1984)
1980		1	1	1	1	Turbo Goose	Ljungblad (1981); Hobbs and Goebel (1982)
"				1		Twin Otter, Islander	Renaud and Davis (1981)
"				1		Cessna 337	Fraker and Fraker (1981)
"				1		Islander	Fraker *et al.* (1982)
1983	2					Sikorski H-52-A	Brueggeman (1987)
"		1		1	1	Turbo Goose	Ljungblad *et al.* (1984a)
"				1	1	Turbo Goose	Ljungblad *et al.* (1984b)
"				1	1	Twin Otter	Ljungblad *et al.* (1984b)
"				1		Twin Otter, Islander	Richardson *et al.* (1984)
"				1		Twin Otter	McLaren and Davis (1985)
				1		Turbo-Commander	Cubbage *et al.* (1984)
1986	1					P-3 Orion	Ljungblad (1986)
"		1				Twin Otter	Rugh (1990)
"				1	1	Turbo Goose	Ljungblad *et al.* (1987)
"				1	1	Twin Otter	Ljungblad *et al.* (1987)
"				1	1	Twin Otter	Richardson *et al.* (1987b)
"				1	1	Twin Otter	Davis (1987)
				3	1	Twin Otter	Ford *et al.* (1987)
Total	4	4	1	19	11		

[1] Some additional types of aircraft may have been used to a lesser extent.

overall occupied range. It is, of course, not possible to determine the exact amount of disturbance that each individual or group of bowheads has been exposed to during the 13 year study period. It is, however, possible to detect major differences in amount of disturbance to the majority of animals in the DSS and BBS. These are summarized in Table 30.

Subsistence-related Vessel Traffic

During the winter, spring and early summer periods there is very little subsistence-related vessel traffic in the range of either the DSS or the BBS. However, there is substantial subsistence whaling in the range of the BBS. Occasionally this whaling involves pursuit of bowheads by outboard-powered small boats. However, silent skin-boats or umiaks are used more commonly. The spring bowhead hunt is intense and occurs from seven communities. In addition to the occasional disturbance from boat noise, there must be a highly intensive disturbance associated with the actual hunting of the whales.

In late summer there is moderately more subsistence-related boat traffic in the DSS area, where more hunters use outboards to pursue small whales and seals, than in the BBS area. Some of the hunting in the former area occurs in fiords and inlets of north Baffin Island that are used by summering bowheads. There are lower levels of boat activity in the BBS area and for the most part this activity does not occur in areas used by bowheads. The exception is the boat-based bowhead hunt that begins in early September in some years at Kaktovik. Substantial numbers of whales can occur near Kaktovik in the late summer and fall, creating the possibility for significant numbers to be disturbed by this hunt.

The autumn hunt also occurs at Cross Island (Nuiqsut) and Barrow. Again, significant numbers of bowheads can be disturbed by the hunt and its associated boat traffic. The levels of other subsistence-related boat traffic are moderate in the DSS area in late September but much less thereafter. Non bowhead-related subsistence traffic in the BB S area is probabl y somewhat lower than that in the DSS area.

Overall, the subsistence activity of most significance with regard to bowhead disturbance is the intensive spring and fall bowhead hunt in the western arctic. The hunt is directed specifically at the animals of concern, unlike the hunts for other species that only incidentally influence bowheads. The number of whaling crews averaged 84 in spring and 9 to 19 in fall. Also the spring hunt occurs when the BBS is very concentrated in coastal lead systems; the fall hunt occurs in nearshore waters along the south edge of the main fall migration route, Thus, hunting activities have the potential for disturbing large numbers of whales and a relatively high proportion of the BBS. For these reasons, it is concluded that the disturbance resulting from subsistence-related activities is significantly higher in the BBS area.

Commercial Fishing Activity

The available data suggest that there is virtually no commercial fishing activity in the range of the BBS during periods when the stock is present. The only caveat to this conclusion is the lack of data from Soviet waters. However, it is unlikely that commercial fishing is frequent during the late fall and winter periods when bowheads are present in the largely ice-covered western Bering Sea.

Table 30. Relative levels of human activities with the potential to disturb bowheads in the DSS and BBS ranges, by season. The number of symbols represents the relative amount of human activity. Size of symbols indicates whether human activity is often in parts of that season's range with many (large circles) or few (small circles) bowheads. Solid symbols indicate activities that are specifically targeted at bowheads.

	DSS					BBS				
	Winter	Spring	Early Summer	Late Summer	Autumn	Winter	Spring	Early Summer	Late Summer	Autumn
Bowhead Hunting							● o@		●	●●
Other Subsistence			o	ooo	oOo			o	oo	oO
Commercial Fishing	oo	ooo	o	o	o					o?
Marine Seismic				oo	OO			o	OOO	OOO
Offshore Drilling		o						o	OOO	OO
Commercial Vessels	o	o	o	oO	o	o	o	o	OoO	OoO
Coastal Airstrips	o	oo	o	oo	oo	o	OO	o	O	O
Low-level Helicopter		o	o	oo	oo	o	o	ooo	OOO	OOO
Low-level Aerial Surveys	o	o	OO	oO	•	●	●	•	●O●	● ●

Commercial fishing is more prevalent in the DSS range where there was an average of 2,002 vessel-days per year, equivalent to an average of 5.5 fishing vessels per day, However, most of this fishing activity occurs in parts of the range that contain few, if any, whales. For example, the heaviest fishing effort occurs in spring (905 vessel-days). However, during this season, virtually all bowheads are present within areas of pack ice whereas all fishing is likely to be in areas without significant pack ice. Furthermore, bowheads are moving north through the pack ice in spring and are unlikely to be near the pack-ice edge where noise from the fishing boats would be most prominent. Similarly, bowheads are likely to be in pack-ice areas in late autumn and winter and will again avoid interactions with fishing vessels. During the open water season in late summer and early fall, DSS bowheads are concentrated in the channels of the arctic islands and in coastal waters where they are not close to the offshore fishing activities.

The above analyses indicate that substantially more commercial fishing occurs in the DSS area than in the BBS area. However, when the incidence of potential disturbances is assessed, it is clear that few bowheads are likely to be disturbed during the course of a year and that commercial fishing is not a significant disturbance factor for DSS bowheads.

Marine Seismic Activity

The most intense underwater sounds to which bowheads are exposed are those emitted during seismic exploration using air gun arrays towed behind slowly moving ships. Seismic exploration apparently was more common in the DSS area than in the BBS area in the first two years (1974-75) of our 13 year study period. However, seismic was more common in the BBS area in the remaining 11 years of the period. During the late summer period when direct comparisons of seismic levels in the two areas were possible, the amount of seismic exploration was over three times as much in the BBS area as in the DSS area. The ‘over 3x’ factor is a minimum because the comparison excludes any seismic activity that may have occurred in the Soviet part of the range of the BBS.

By its nature, ship-based seismic exploration can only be conducted in ice-free waters. Most seismic in the BBS area has been conducted in the southern Beaufort Sea. Much of this has been during periods when bowheads were present in the region. For example, the southeastern Beaufort Sea is a major summering area for bowheads and it has also been the focus of the seismic activity conducted for Canadian oil companies. Similarly, a significant fraction of the seismic exploration in the autumn has occurred in parts of the southern Beaufort Sea that are occupied by feeding and migrating bowheads. Thus, the greater amount of seismic exploration in the heart of the summer and fall range of the BBS has subjected the BBS to substantially greater seismic disturbance than experienced by the DSS.

Commercial Vessel Traffic

Commercial vessel traffic includes government and oil industry icebreakers, freighters, small tankers, tug/barge combinations, drillships and bottom-founded drilling structures, dredges, oil industry support vessels, research vessels, cruise ships, and coastal passenger vessels along west Greenland. Some of these commercial vessels produce intense underwater noise that can be detected at long distances. Unlike seismic pulses, which are intermittent, ships emit continuous noise. When vessels operate at a fixed site, e.g., a drillsite, the noise can be continuous over periods as long as several weeks.

Commercial vessel traffic levels in winter are trivial in both the DSS and BBS areas. Shipping levels in spring are higher in the DSS area (125 vessel-days/year) than in the BBS area (virtually no spring vessel traffic). This difference may not be significant since most of the DSS traffic is along the Greenland coast or south of the pack ice and is not directly through areas occupied by bowheads.

Shipping activity is naturally much greater during the ice-free periods of summer and early autumn. This is particular y pronounced in the BBS area in early summer when offshore drilling and associated activities begin. Between 24 and 33 vessels operated in the BBS in the early summer periods compared with only 6 in the DSS area. Also, vessels tended to operate for longer periods in the BBS than in the DSS area. Thus, levels were at least 4 to 5 times higher in the BBS range.

Shipping activity peaks in the late summer period. An average of 25 vessels entered the DSS area in this period and spent about 364 vessel-days there per year. By contrast, 62 vessels were present in the Canadian Beaufort Sea in the late summer of 1985, which was not a peak year for oil industry activity in the area. The number of vessel-days has not been calculated. However, most of these vessels spend the entire 46-day late summer period in the BBS area, so the overall level of activity must be about 4-5 times higher than in the DSS area. Furthermore, much of the BBS traffic occurs in important summering areas for bowhead whales, whereas the DSS traffic is more widely distributed through the overall range of the DSS, much of which is--at most--sparsely occupied.

The patterns of vessel traffic noted in late summer carry over into autumn. Offshore drilling continues until mid-October in the southern Beaufort Sea. The available data suggest that the amount of commercial vessel traffic in autumn is at least three times as high in the BBS area as in the DSS area. Again the BBS traffic is concentrated in the southern Beaufort Sea, which includes the main fall migration route for the BBS bowheads. Considerable commercial vessel traffic also occurs in Soviet waters that bowheads are known to frequent in autumn. Ship traffic in the DSS area avoids the coastal concentration areas used by DSS bowheads in autumn.

Overall, it is clear that BBS bowheads have been exposed to much higher levels of potentially disturbing vessel noise than have animals of the DSS.

Low-level Aircraft Flights

Low-1evel aircraft flights have the potential to disturb bowhead whales. However, the type of disturbance is qualitatively and quantitatively different than disturbance by vessels. Aircraft disturbance occurs within very short time periods. The rapid onset of noise often leads to short-term startle responses. This contrasts with vessel noise, which increases gradually and can last from perhaps one hour to a few hours or, in the case of a stationary operation, weeks. Three types of low-level flights were evaluated for their disturbance potential: flights associated with coastal airstrips, helicopter traffic associated with ice-breakers and offshore oil exploration, and low-level biological research flights.

Although there are numerous airstrips in the range of the DSS, few are present near areas where bowheads are common and the probability y of disturbance is low. There are more coastal airstrips in Soviet, U.S. and Canadian parts of the BBS area. Three of them are near areas where bowheads frequently concentrate and disturbance is likely. These are Barrow in the spring and fall, and Komakuk and Stokes Point in the late summer and autumn.

Helicopter traffic over marine areas is relatively light in the DSS area, Small utility helicopters are carried by Canadian Coast Guard icebreakers to conduct ice reconnaissance near the ships in spring and summer. About five helicopters are involved in the DSS area, at least intermittently. Substantially greater numbers of helicopters are associated with offshore oil exploration in the BBS range where an average of about 11 medium-sized twin-engined helicopters have been used from early summer to autumn. Much of this activity occurs in and near the important summering range in the southeastern Beaufort Sea and the major fall migration route through the southern Beaufort Sea.

Low-level research flights often occur in areas where bowheads concentrate, since bowheads are often the specific objects of the survey flights. During the five sample years that were examined, there were approximately half as many aircraft-seasons in the DSS area (20) as in the BBS area (39). Furthermore, a much higher proportion of the surveys in the BBS area were directed specifically at bowhead whales.

Overall, it appears that the numbers of low-level flights were at least twice as high in the BBS area as in the DSS area. In addition, more of the flights in the BBS area were in areas where bowheads concentrate and thus were likely to disturb bowheads. Thus, the levels of potential disturbance were well over twice as high in the BBS area as in the DSS area.

Integration of Overall Activity Levels

This report has examined six broad categories of human activities that occur in the ranges of the Davis Strait and Bering/Beaufort stocks of bowhead whales. The six categories are subsistence-related vessel traffic, subsistence whaling directed at bowheads, commercial fishing activities, marine seismic surveys, commercial vessel traffic including offshore drilling, and low-level aircraft flights of three types. Clearly these activities differ markedly in their capability to disturb bowhead whales. The following paragraphs attempt to account for these differences while integrating the various activities to determine the overall relative disturbance levels faced by each of the stocks. Table 30 summarizes this analysis.

It can be argued, at least on an intuitive basis, that the subsistence hunt for bowheads is the single most disturbing stimulus encountered by the whales. This hunt occurs only in the BBS area, with intensive efforts in both spring and--to a lesser degree--fall.

The next most disturbing activities are probably commercial vessel traffic and marine seismic surveys (see Richardson et *al.* 1989, 1991 for reviews of disturbances and their effects on marine mammals). Commercial vessel traffic and offshore drilling create substantial underwater noise for extended periods. The activities were found to be at least 4-5 times more prevalent in the BBS area than in the DSS area. Furthermore, the proportion of the commercial vessel traffic occurring in areas important to bowheads was much higher in the BBS than in the DSS area.

Marine seismic involves extremely intense energy pulses at regular intervals, usually 8 to 12 seconds, when survey lines are being shot. Over three times as much seismic was shot in the BBS area as in the DSS area during the 13 year study period. Again, a higher proportion of the seismic shot in the BBS area was shot in areas that were important to bowhead whales.

Low-level aircraft flights are likely to startle bowheads and to cause mostly short-term responses. Overall, the numbers of low-level flights were about twice as great in the BBS area. Also, the flights were more likely to occur over the specific areas used by bowheads in the BBS area than in *the* DSS area.

Boat traffic related to subsistence activities involves mainly outboard-powered small boats. When the bowhead hunt is excluded from consideration, there is marginally more subsistence-related boat traffic in the DSS area than in the BBS area. Some of this traffic in each area takes place in waters occupied by bowheads, at least on occasion. Commercial fishing is essentially restricted to the DSS area. However, this activity is unlikely to disturb DSS bowheads because most of the commercial fishing activity occurs in parts of the range that are nearly unused by bowheads,

It is not possible to calculate an entirely objective index of human activity levels in the ranges of each of the stocks over the 13 year study period. However, based on the previous evaluations and assessments it is possible to conclude that bowheads of the Bering/Beaufort stock have been subjected to at least 3 to 5 times as much human activity as have the bowheads of the *Davis* Strait stock. This conclusion is based on the numerical estimates of human activity and on a consideration of the relative importance of each activity type, given what is known about their potentials for disturbing bowheads.

CONCLUSIONS

Phase *2* of this study demonstrated conclusively that, as suspected, bowhead whales of the Bering/Beaufort stock have been subjected to much more human activity than have bowheads of the Davis Strait stock. It was estimated, in the previous section of this report, that the potential for disturbance was 3-5 times higher in the western arctic during the 13 year period from 1974 to 1986. The major activities most responsible for these differences in disturbance potential were commercial vessel traffic including offshore drilling, marine seismic exploration, aircraft overflights, and the subsistence hunt for bowhead whales in spring and autumn (Table 30). The differences in human activity levels in the western and eastern arctic were fairly consistent throughout the 13 year period. Thus, there was a long-term difference in exposure levels.

The behavior patterns of Bering/Beaufort and Davis Strait bowheads were compared in Phase 1 of this study (Richardson and Finley 1989). The Phase 1 report provides the first detailed quantitative data on the behavior of the Davis Strait bowheads, and indeed on any bowhead stock other than the much-studied Bering/Beaufort population. This has allowed important comparisons of the behavior patterns of these two populations. The findings of Phase 1 that are relevant to the overall hypotheses to be tested in this study are summarized earlier in the present report--see ‘Summary of Behavioral Comparisons (Phase l)’.

The null hypothesis that there are no significant differences in the normal (= undisturbed) behavior between bowheads of the Bering/Beaufort and Davis Strait stocks is rejected by the data from Phase 1. There are statistically significant differences in the behavior of the two stocks (Table 1). There are also major differences in the levels of the potential y-disturbing human activities to which each stock was subjected during the study period. However, this does not necessarily mean that the differences in human activities were the cause of the observed differences in behavior.

As has been recognized from the outset of this project, it is extremely difficult to ascribe observed differences in behavior to the cumulative effects of long-term human activities. It is not possible to isolate discrete, independent units of observation for the eastern or western populations; thus, a statistical approach is not appropriate. The final conclusions must rest on a "weight of evidence" approach that evaluates all of the potential factors that might reasonably influence the observed behavior patterns, This approach was used in the Phase 1 report.

Phase 1 documented that, although the basic behavioral repertoires of the two stocks were similar, there were some statistically significant differences. These differences were evident for each of the three categories of whales that could be compared: whales feeding in the water column in deep water, whales socializing in shallow water, and whales migrating during autumn.

The regional differences in the behavior of feeding and socializing whales can most easily be explained by the substantial differences in water depth and age of the animals, respectively, (Richardson and Finley 1989). It is not known whether the regional differences in human activity levels were a factor.

The regional differences in the behavior of bowheads during autumn migration cannot be so easily explained by environmental conditions. Bowheads of the Bering/Beaufort stock had longer dive durations and less-frequent fluke-out dives than did fall-migrating bowheads of the Davis Strait stock. Given that most of the behavioral variables examined did not differ significantly between migrants in the two regions, it is difficult to evaluate the biological significance of the two statistically significant differences that were found.

It is interesting to note, however, that the two significant behavioral differences in autumn have the effect of rendering the Bering/Beaufort bowheads less detectable during the fall migration. These animals spend less time at the surface and exhibit fewer fluke-out dives. Interestingly, it is even more uncommon for bowheads migrating near Pt. Barrow, Alaska, in spring to fluke-out upon diving (Richardson *et al.* 1990a and in prep.). The proportions of the dives that begin with flukes-out are 9% near Barrow in spring (1989-90 data), *27%* in the Alaskan Beaufort in autumn, and 58% in Baffin Bay in autumn, considering traveling bowheads exclusive of mothers and calves. There are no data on behavior of spring-migrating bowheads in the Davis Strait area, so it is not known whether the low frequency of fluke-out-dives in the BBS area in spring, where bowheads are hunted, differs from behavior in the DSS area, where they are not hunted.

It is possible that BBS bowheads have adopted these behaviors at least partly in response to the increased industrial disturbance in the Beaufort Sea. However, it seems more likely that these behaviors are in response to the fairly intensive subsistence whaling that has occurred along the migration routes of the Bering/Beaufort stock for many decades. Behavior that makes migrating bowheads less detectable by Inupiat whalers would have survival value for bowheads.

There is some evidence that in the presence of nearby boats, gray whales make themselves less conspicuous by exhaling underwater and exposing their blowholes only to inhale (Hubbs and Hubbs 1967; Zimushko and Ivashin 1980; M. Bursk *in* Atkins and Swartz 1989:11). Cummings and Thompson (197 1) also observed this inconspicuous or 'snorkeling' behavior in response to playbacks of killer whale sounds. Thus, the behavior changes that tend to make bowheads less conspicuous during migration in the Beaufort Sea may not be a unique adaptation among baleen whales.

One difference between the two populations remains unexplained. That is the high degree of sexual activity observed at Isabella Bay, Baffin Island. Sexual activity is rarely observed in the Beaufort Sea during late summer or autumn (Richardson and Finley 1989), although several cases were observed in 1988 (Würsig *et al.* 1990). This difference *seems* to persist even when the comparisons are restricted to areas with adult and large subadult animals--the types of animals at Isabella Bay. The cause(s) and significance of this apparent regional difference in sexual interactions in late summer are totally unknown.

The primary analyses in this study were based on comparisons of the 'normal' behavior of bowheads in the two regions in order to determine whether there was evidence of long-term, cumulative effects of human activities on the behavior of bowheads. In interpreting the possible long-term effects of disturbance, it is useful to know whether the two populations exhibit differences in their short-term responses to human activities. Limited data were available on the reactions of Davis Strait bowheads to small boats and aircraft (Richardson and Finley 1989). Many data are available on the reactions of Bering/Beaufort bowheads to boats and aircraft (Richardson and Malme, in press).

In the face of the relatively intense human activity levels in the Bering/Beaufort area, it is possible that bowheads there would respond to disturbance differently than would whales in the Davis Strait area. This apparently happens in the beluga whale, which is more tolerant of human activities in areas where levels of human activity are intense than in areas, such as the eastern Canadian arctic, where levels are much lower (Davis and Thomson 1984; Finley *et al*, 1990; Richardson *et al. 1991).* Belugas have apparently habituated to noise and disturbance in some areas. The available data were examined to see if there was any suggestion that bowheads in the western arctic are showing signs of habituating to the existing levels of disturbance.

Bowheads reacted strongly to small boats in both the eastern and western arctic. In both regions, reactions to slow-moving boats were less dramatic but avoidance was still evident. In both areas, there was evidence that bowheads often resumed their normal activities shortly after the boat had passed. Detailed quantitative comparisons were not possible but the available information suggests that sensitivity to small vessels is similar in the two regions.

During some low-level overflights by aircraft, bowheads dive hastily in both the eastern and western arctic. During other such overflights, the whales remain at the surface and seem unaffected. Bowheads seem to be less sensitive to aircraft when actively engaged in social interactions. Although comparative data are limited, sensitivity to aircraft seems similar in the two regions.

Therefore, based on the available information regarding reactions to small boats and low-flying aircraft, there is no evidence that the Bering/B eaufort population is habituating to the much higher levels of human activity to which they are exposed. It is possible that, with more data, detailed quantitative analysis might show lower responsiveness in the western arctic. However, at present there is no evidence of the marked regional differences in responsiveness exhibited by beluga whales in these two regions.

In summary, there are detectable differences in the behavior of the Bering/Beaufort and Davis Strait stocks of bowheads but only the differences during fall migration seem likely to be related to human activity. The reason(s) for the regional differences during autumn are uncertain, but the most likely explanation is the ongoing exposure of B.ering/Beaufort bowheads to subsistence whaling. There is no evidence that the Bering/Beaufort stock has habituated to the existing levels of human activity.

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APPENDIX 1

Summary of 'Industry' Seismic Programs
with the Potential to Influence DSS Bowheads,
1974-1986

Appendix 1. Summary of 'industry' seismic programs with the potential to influence DSS bowheads, 1974-1986.

Year	Company	COGLA Project No.	Contractor	Vessel	Km of Seismic Shot: 1 Aug-15 Sep	Km of Seismic Shot: 16 Sep-31 Dec	Total	Location
1974	Texaco	017-09-12-062	GSI	*Arctic Explorer*	136.8		136.8	Baffin Bay (NE Baffin Island)
"	Great Plains	076-09-10-036	GSI	*Arctic Explorer*	558.5		558.5	Kane Basin
"	GSI	838-09-10-004	GSI	*Carino*	1,500.0		1,500.0	Wellington Channel-Penny Strait
"	Gulf	002-09-12-99	GSI	*Carino*		1,660.9	1,660.9	Smith Sound
'	Esso	007-09-12-173	GSI	*Arctic Explorer*		581.7	581.7	Davis Strait (Cumberland Sound)
'	Aquitaine	673-09-12-60	CGG	*Orion* Arctic		1,475.8	1,475.8	Davis Strait (Cumberland Sound-Frobisher Bay)
"	Total				2,195.3	3,718.4	5,913.7	
1975	AIOG	054-09-10-93	GSI	*Arctic Explorer*	1,565.7		1,565.7	Wellington Channel, Pcmy Strait
"	Norlands	511-09-09-016	CGG	*Polar B Jorne*	792.9		792.9	Wellington Channel
'	"	"	"	"	513.5		513.5	Eastern Lancaster Sound
'	"	"	"	.		1,612.5	1,612.5	Baffin Bay (Philpots Island)
'	Shell	037-09-12-159	GSI	*Indian Seal*	2,011.8		2,011.8	Baffin Bay (NE Bylot Island)
'	Eureka	528-09-12-009	GSI	*Arctic Explorer*	76..0	2,208.0	2,284.0	Baffin Bay (E Baffin Island)
'	Shell	037-09-12-162	GSI	*Indian Seal*	117.9	3,889.5	4,007.4	Davis Strait (Cape Dyer)

Continued...

Appendix 1. Continued.

Year	Company	COGLA Project No.	Contractor	Vessel	Km of Seismic Shot: 1 Aug-15 Sep	16 Sep-31 Dec	Total	Location
1975	Aquitaine	673-09-12-075	CGG	*Orion Arctic*		965.5	965.5	Davis Strait (Resolution Island)
.	Shell	037-09-12-146	GSI	*Indian Seal*		274.5	274.5	Davis Strait (Cumberland Sound)
"	BP	039-09-12-037	CGG	*Polar Bjorne*		635.7	335.7	Davis Strait (Cumberland Sound)
"	City Services	062-09-12-47	CGG	*Dauphine de Cherbourg*		1,699.5	1,699.5	Baffin Bay (Hoare Bay)
"	.	.	.	Polar Bjorne				"
.	Total				5,077.8	11,285.2	16,363.0	
1976	AIOG	054-09-10-113	GSI	*Arctic Explorer*	840.0		840.0	High Arctic Islands 77°N, 98°W
.	AIOG	054-09-10-103	GSI	*Arctic Explorer*	302.6		302.6	"
"	Mobil	057-09-10-99	GSI	*Arctic Explorer*	92.1		92.1	"
"	GSI	838-09-10-009	GSI	*.4 retie Explorer*	371.0		371.0	"
"	Norlands	511-09-12-19	GSI	?		56.3	56.3	Baffin Bay (Philpots island)
"	Shell	037-09-12-161	GSI	*Arctic Explorer*		524.0	524.0	Baffin Bay (NE Bylot Island)
"	Eureka	528-09-12-13	GSI	*A retie Explorer*		85.9	85.9	Baffin Bay (Pond Inlet)
"	Shell	037-09-12-168	GSI	?		1,059.0	1,059.0	Davis Strait (Cape Dyer)

Continued...

Appendix 1. Concluded

Year	Company	COGLA Project No.	Contractor	Vessel	Km of Seismic Shot 1 Aug-15 Sep	16 Sep-31 Dec	Total	Location
1979	Ram	834-09-12-03	GSI	*Arctic Explorer*		*60.0*	*60.0*	Davis Strait (Frobisher Bay)
"	Esso	007-09-12-363	GSI	*Olga Bravo*		1,151.1	1,151.1	Davis Strait (Cumberland Sound-Frobisher Bay)
	Total				760.9	6,062.2	6,823.1	
1980	Aquitaine	673-09-12-84	GSI	*Arctic Explorer*		*459.1*	*459.1*	Davis Strait (Frobisher Bay)
"	"	"	"	*Brandal*		*381.0***	*381.0***	
"	"	*673-09-12-88*	·	*Arctic Explorer*		310.1	*310.1*	Davis Strait (Cumberland Sound)
·	Total					1,150.2	1,150.2	
1981	Aquitaine	673-09-12-90	GSI	*Agnich*	17.9	1,553.3	1,571.2	Davis Strait (Cumberland Sound)
	"	"	"	*Brandal*		831.0**	831.0**	Davis Strait (Cumberland Sound)
"	Total				17.9	2,384.3	2.402.2	

* High resolution seismic reflection.
** Marine dynamite refraction survey.