Environmental
Studies
Revolving
Funds

009 Bowhead Whale Monitoring Study in the Southeast Beaufort Sea, July-September 1984

Canada

August 1985

The Environmental Studies Revolving Funds are financed from special levies on the oil and gas industry and administered by the Canada Oil and Gas Lands Administration for the Minister of Energy, Mines and Resources, and by the Northern Affairs Program for the Minister of Indian Affairs and Northern Development.

Environmental Studies Revolving Funds
Report No. 009
August 1985

BOWHEAD WHALE MONITORING STUDY IN THE SOUTHEAST BEAUFORT SEA, JULY-SEPTEMBER 1984

Lois A. Harwood
ESL ENVIRONMENTAL SCIENCES LIMITED
Sidney, B.C.

Gary A. Borstad
G.A. BORSTAD LIMITED
Sidney, B.C.

Scientific Adviser: J.G. Ward

The correct citation for this report is:

Harwood, Lois A. and Gary A. Borstad. 1985. Bowhead whale monitoring study in the southeast Beaufort Sea, July-September 1984. Environmental Studies Revolving Funds Report No. 009. Ottawa 99 p.

Published under the auspices
of the Environmental Studies
Revolving Funds
ISBN 0-920783-08-02

TABLE OF CONTENTS

TABLE OF CONTENTS (Continue)

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

FIGURE | Page

LIST OF PLATES

ACKNOWLEDGEMENTS

This study was funded by the Environmental Studies Revolving Funds and Indian and Northern Affairs Canada (INAC) through Northern Oil and Gas Action Program (NOGAP). We would like to thank John Ward of Dome Petroleum Limited and Ricki Hurst of INAC for their continuous support and involvement throughout this investigation. We also thank Michael Kingsley, Canada Department of Fisheries and Oceans (DFO), for permission to include bowhead sighting information collected during the July 1984 offshore white whale program and Pam Norton for providing these data. Records of wildlife sightings by industry and support personnel were provided by Ron Quaife of Esso Resources Canada Limited and by John Ward.

The following people were observers during the field surveys: Lois Harwood, Pam Norton, Ricki Hurst, John McDonald, John Ford, and Jim Darling. The authors and field team would like to thank the many staff of Kenn Borek Air Ltd., Inuvik, NWT, who contributed to a successful field season. In particular, we would like to acknowledge Gord Johnson and pilots A. Dusang, L. Glazier, N. Hageman, B. Allan, D. Bacon, and K. Harvey. During the field program, we appreciated the cooperation of other investigators conducting bowhead studies in the region: D. Ljungblad, D. Rugh, J. Richardson, R. Davis and W. Koski.

Employees of the Atmospheric Environment Service in the Beaufort Weather and Ice Office at Tuktoyaktuk provided daily weather forecasts and reports. Andrew Thomas, Department of Oceanography, University of British Columbia was responsible for reception and copying of the digital satellite imagery. J.F.R. Gower, DFO Institute of Ocean Sciences, Sidney, made the use of the image processing laboratory available for this project. M. Lawrence (DFO), allowed use of imagery and oceanographic data collected for another project to be considered here.

W. Duval and J. Ford conducted an internal review of this report. We thank them, and also external reviewers: J. Ward, R. Hurst, M. Nerini, M. Kingsley, and J. Richardson. We also thank John McDonald and Laurence Turney for assistance with data analysis, Patricia Janvrin, Victoria Wagner and Shirley Huang for word processing and production of the report, and Brian Sawyer for preparation of the figures.

SUMMARY

Systematic aerial surveys were conducted in the southeast Beaufort Sea during the periods 18-27 August and 5-13 September 1984, to document the abundance and distribution of bowhead whales in relation to industrial activity. The study area extended from longitude 141°W (Alaska-Yukon border) to 125°47'W (west Franklin Bay), and from the 2-m isobath seaward to a 7-9/10 concentration of pack-ice. Surface oceanographic conditions at the time of the surveys are described using satellite imagery analyses and in situ temperature data from industry vessels. Bowhead sightings from four additional systematic aerial surveys of the region in July and early August 1984 are also discussed.

Overall bowhead abundance in the southeast Beaufort Sea generally increased throughout the 1984 open water season, although within this period, two periods of peak abundance were apparent. Bowheads were not present in large numbers (probably <300) during the first half of July 1984, but by late July, from 900 to 1500 animals were observed throughout the study area, and were most often seen 50 km east of Herschel Island and near Baillie Islands (21-23 July survey), 100 km offshore of the Tuktoyaktuk Peninsula, and 100 to 200 km offshore of the Yukon coast (28 July-2 August survey).

During the 18-27 August survey, 36 bowheads were observed on transect, 17 bowheads were seen off-transect, and 41 were observed during ferrying flights. Estimated bowhead abundance during this survey was 500 to 800 for the southeast Beaufort Sea, and 300 to 500 for west Amundsen Gulf. A total of 42 bowheads was observed on-transect during the 6-18 September survey; an additional five bowheads were observed off-transect; and 66 were seen during ferrying flights. Estimated bowhead abundance was from 1200 to 1900 in the southeast Beaufort Sea, and from 300 to 500 in west Amundsen Gulf.

The apparent fluctuations in bowhead abundance in the southeast Beaufort Sea coincided with changes in the general distribution and activities of whales observed, and in the oceanography of the area. During the surveys in July, bowheads were generally observed 100 km or further from shore in association with ice, or in cold, clear water. Observed activities during July included only diving, swimming at the surface, and resting. During late August and September, most animals observed were in relatively large groups in nearshore ice-free or open waters. They were feeding and socializing, and were congregated near Cape Bathurst and in Franklin Bay, where satellite imagery showed vigorous convergent surface circulation (22-23 August); 100 km north of Cape Dalhousie (no image available); and near strong oceanographic fronts marking the edge of the Mackenzie plume and an upwelling along the Yukon coast (11-12 September). These types of oceanographic features often attract or concentrate zooplankton in other regions.

The southeast Beaufort Sea has been used by substantial numbers of bowheads during late August and September of the five years in which systematic surveys have been conducted. However, the distribution of bowheads within the areas surveyed has varied markedly among surveys and years, both in areas encompassing industrial activity and in areas outside of the hydrocarbon exploration zone. In August 1980, large numbers of bowheads were congregated within the industrial zone offshore of the Tuktoyaktuk Peninsula. Small numbers were seen there in 1981-1983, and large congregations were observed off the Yukon coast in 1983 and in 1984. Two hypotheses have been formulated to explain these variations. First, that whales may be avoiding the industrial area as a behavioural response to industrial activity, or secondly, that they may be responding to natural, physical, and biological, oceanographic fluctuations, especially those related to food availability. The data from the current study lend support to the latter hypothesis.

Résumé

Du 18 au 27 août et du 5 au 13 septembre 1984, des recensements aériens systématiques ont été effectués au sud-est de la Mer de Beaufort en vue d'évaluer le nombre et de déterminer la répartition des baleines franches par rapport à l'activité industrielle déployée dans cette région. Ces relevés devaient couvrir une superficie s'étendant de la frontière qui sépare l'Alaska du Yukon (à 141° de longitude ouest) jusqu'à l'ouest de la Baie de Franklin (à 124°47' de longitude ouest) et à partir de l'isobathe de 200 milles nautiques vers la mer jusqu'à une concentration de 7 à 9/10 du champ de glace. Les conditions océanographiques de surface à cette époque y sont décrites d'après l'analyse des photos prises par satellite et les données de température in situ provenant de navires industriels. On fait également état de quatre autres levés aérophotogrammétriques systématiques effectués dans la région, en juillet et au début du mois d'août 1984, et portant sur les baleines franches.

La population globale de ces cétacés dans la région du sud-est de la Mer de Beaufort s'est accrue pendant toute la saison 1984, au cours de laquelle elle a connu cependant deux périodes de pointe. Alors que pendant la première moitié de juillet 1984 on ne comptait guère plus de 300 baleines franches, on pouvait en revanche en dénombrer de 900 à 1 500 vers la fin de juillet. Celles-ci étaient aperçues le plus souvent à 50 kilomètres à l'est de l'Île Herschel et près des Îles Baillie (levé du 21 au 23 juillet), à 100 kilomètres au large de la Péninsule de Tuktoyaktuk et à 100 ou 200 kilomètres au large de la côte du Yukon (levé du 28 juillet au 2 août).

Au cours des vols effectués entre le 18 et le 27 août, il a été possible d'observer 36 baleines franches le long des lignes d'observation, 17 autres se démarquant de cette zone et 41 hors champ d'observation. On a ainsi évalué entre 500 et 800 le nombre de baleines localisées au sud-est de la Mer de Beaufort et entre 300 et 500 le nombre de celles se trouvant à l'ouest du Golfe d'Amundsen. Au cours de la période allant du 6 au 18 septembre, on a observé au total 42 baleines sur le parcours du relevé, cinq autres se détachant de celui-ci et 66 en dehors de la ligne d'observation. On a donc estimé que la densité de la population des baleines franches était de 1 200 à 1 900 animaux au sud-est de la Mer de Beaufort, contre 300 à 500 à l'ouest du Golfe d'Amundsen.

Ces variations évidentes dans la population des baleines au sud-est de la Mer de Beaufort dépendaient en fait des changements survenus dans leur répartition et leurs activités et des conditions océanographiques de la région. Au cours des levés effectués en juillet, ces cétacés se tenaient généralement à 100 kilomètres ou plus du littoral, circulant dans des eaux claires, froides ou glacées et limitant leurs activités à plonger, à nager et à se reposer. Vers la fin du mois d'août et en septembre, la plupart des animaux observés formaient de larges troupeaux près du littoral sans glace ou au large. Vivant en groupe et se nourissant, ils se trouvaient rassemblés notamment près du Cap Bathurst et de la Baie de Franklin où les photos prises par satellite avaient révélé une intense circulation en ligne convergente (les 22 et 23 août), à 100 kilomètres au nord du Cap Dalhousie (aucune image n'est disponible), ou près des solides fronts océanographiques marquant le contour du Mackenzie et une remontée d'eau le long de la côte du Yukon (les 11 et 12 septembre). Ces traits océanographiques caractéristiques attirent souvent des concentrations zooplanctoniques d'autres régions.

Le sud-est de la Mer de Beaufort a été le lieu d'élection d'un nombre important de baleines franches vers la fin du mois d'août et en septembre, pendant les cinq années au cours desquelles les relevés systématiques ont été effectués. Il n'en reste pas moins que la distribution de ces animaux a considérablement varié au fil des ans et des études, dans les régions où étaient déployées les activités industrielles et dans celles situées en dehors de la zone d'exploration des ressources en hydrocarbures. Au mois d'août 1980, un nombre considérable de baleines franches s'était rassemblé dans la zone industrielle au large de la Péninsule de Tuktoyaktuk, alors qu'entre 1981 et 1983 celui-ci y était beaucoup plus restreint. En 1983 et 1984, on a pu par ailleurs en observer de grands troupeaux au large de la côte du Yukon. Pour tenter d'expliquer ces variations dans le comportement des baleines, deux hypothèses ont été émises: soit celles-ci désiraient éviter les activités industrielles, soit elles suivaient tout simplement les fluctuations océanographiques naturelles, physiques et biologiques dans la recherche de leur nourriture. Les données fournies par l'étude en cours semblent corroborer cette dernière hypothèse.

INTRODUCTION

The western Arctic population of bowhead whales (Balaena mysticetus) winters among pack-ice in the Bering Sea and migrates annually to summering areas in the Beaufort Sea and in Amundsen Gulf. From about late June through September, a portion of the population occurs in some areas where offshore hydrocarbon exploration is active in the Canadian Beaufort (Richardson et al. 1984). The potential effects of these activities on the bowhead population are an area of concern (e.g., FEARO 1984; LGL et al. 1984; ESL et al. 1985).

Before commercial exploitation, the bowhead whale was present throughout Arctic and sub-Arctic waters in five presumably discrete stocks. However, commercial harvest of this species throughout its range resulted in depletion of all populations. The western Arctic stock was the last to be exploited and is the largest remaining bowhead population, having approximately 75 per cent of the world's bowheads. Estimates of pre-exploitation stock size range between 14,000 and 26,000 (Breiwick et al. 1981). The International Whaling Commission's accepted estimate of the size of this population is 3871 (standard error 254) (IWC 1984). The bowhead whale has been protected from commercial whaling activity since 1931 by the International Convention for the Regulation of Whaling, and is considered an endangered species by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and the International Whaling Commission (IWC).

The present study was the fifth consecutive year of systematic aerial surveys for bowheads in the Canadian Beaufort Sea. The results of past surveys in this series (Renaud and Davis 1981; Davis et al. 1982; Harwood and Ford 1983; McLaren and Davis 1985) indicate that the late summer distribution of bowheads varies markedly between, and within, years. In 1980, the first year of bowhead systematic surveys in this series, the industrial development zone was extensively used by bowhead whales. The number of bowheads seen in the industrial zone was much lower in the 1981-83 surveys. Two alternate hypotheses have been formulated to explain the differences in bowhead whale distribution from 1980 to 1983 (LGL et al. 1984; ESL et al. 1985):

- industrial activity has caused, or contributed to, a progressive exclusion of bowheads from the development zone; or

- the distribution of bowheads and annual variability in distributional patterns are determined by physical and biological oceanographic factors, particularly those influencing large-scale differences in the distribution and abundance of zooplankton.

The present study contributes information for the eventual evaluation of these hypotheses, but was not specifically designed to test either.

There is very little information concerning zooplankton distribution and abundance in the Canadian Beaufort Sea (Grainger 1975; Griffiths and Buchanan 1982), but Borstad (1985a) recently reported that bowheads tended to congregate near temperature and water colour gradients visible in satellite imagery. Elsewhere, zooplankton are commonly concentrated at oceanographic features that manifest themselves as surface fronts or gradients (Pingree et al. 1975; Mackas et al. 1980; Aiken 1981). The oceanography of baleen whale feeding grounds in high latitudes has been the subject of considerable study (Nemoto 1959; Nasu 1966; Best 1967; Nemoto and Kawamura 1977). Nasu (1966) has classified baleen whale feeding grounds into three major classes:

- ocean fronts between major water masses
- oceanic eddy grounds either along fronts or as a result of topography
- upwelling areas.

As early as 1962, Nemoto (1962) correlated abundance of fin whales with abundance of immature Euphausia superba and changes in current patterns around Antarctica.

The primary objective of the present study was to monitor the relative abundance and distribution of bowhead whales in relation to activities of the oil and gas industry in the southeast Beaufort Sea during the last half of August and the first half of September 1984. An additional objective of the program was to determine the existence of any relationships between oceanographic fronts or upwellings shown in satellite imagery and the observed distribution of bowhead whales. The program conducted to meet these objectives was expanded through the Northern Oil and Gas Action Program (NOGAP) by Indian and Northern Affairs Canada. The NOGAP portion of the study involved extension of the seaward boundary of the Environmental Studies Revolving Funds (ESRF) study area to a 9/10 concentration limit of pack-ice and eastward into Franklin Bay, to determine the relative abundance and distribution of bowhead whales in portions of their summer range other than where past surveys have focused. The boundaries of the ESRF and NOGAP study areas are shown on Figure 1. These programs were fully integrated during the field surveys and the results discussed together throughout this report.

Four systematic aerial surveys of the southeast Beaufort Sea were completed for the Department of Fisheries and Oceans during July and early August 1984 to examine the use of the offshore Beaufort by white whales (Norton and Harwood 1985). Observations of bowhead whales during these four surveys were analysed as part of the present study, and are discussed with the results of the late August and September bowhead surveys.

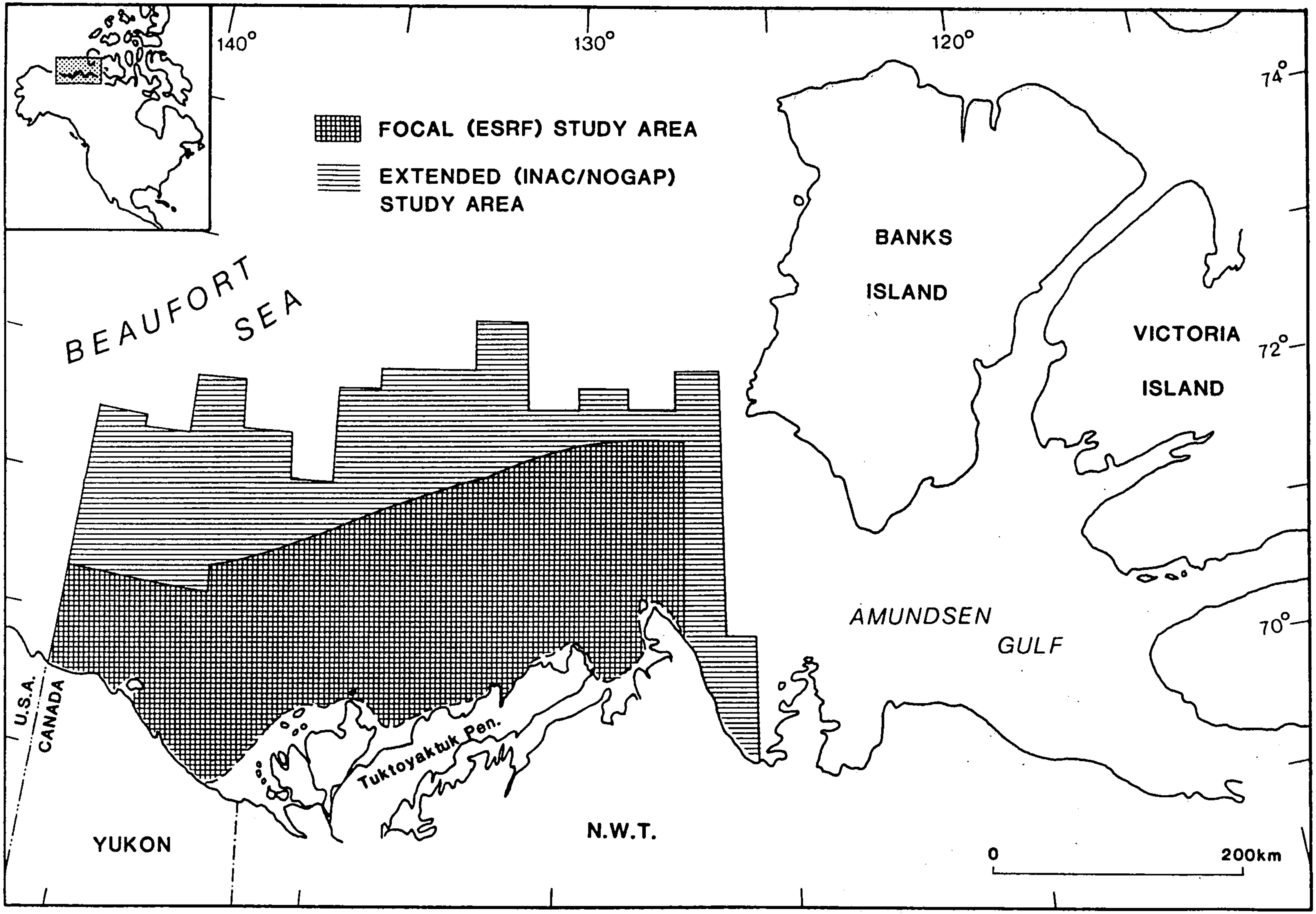


Figure 1. Areas systematically surveyed for bowhead whales, August-September 1984.

METHODS

AERIAL SURVEYS -- LATE AUGUST AND SEPTEMBER

Survey Design

Systematic aerial surveys of the southeast Beaufort Sea were conducted during the periods 18-27 August and 6-18 September 1984. The combined study area of the ESRF and NOGAP programs extended from longitude 141°W (Alaska-Yukon border) to longitude 125°47'W (west Franklin Bay), and from the 2-m isobath seaward to the edge of the 7-9/10 ice cover (Figure 2). The size of the study area was approximately 114,390 km^2 in late August and 96,000 km^2 in September.

Twenty-nine north-south transect lines at intervals of 20 km were established in advance of the surveys within the study area boundaries. The transect width was 2 km, giving about 10 per cent survey coverage of the study area. An additional 23 transect lines were surveyed in three areas of the Beaufort Sea where bowheads were concentrated during late August 1984. These areas and the approximate survey coverage attained in each were: Cape Bathurst and Baillie Islands (30 per cent), Franklin Bay (50 per cent), and Herschel Island (50 per cent). Co-ordinates for the start and endpoints of each survey transect line are provided in Appendix 1, while the size of the study areas and per cent survey coverage for each 1984 survey are given in Appendix 2.

The study area was stratified to allow comparison of bowhead densities calculated in the present study with those from past studies (see Figure 2). Except for three new zones designated during the late August survey (Herschel, Baillie, and Franklin), boundaries of the zones used in this study (Yukon, Delta, Tuktoyaktuk Peninsula, West Amundsen) are the same as those established during 1981 systematic bowhead surveys in the region (Davis et al. 1982) and used in subsequent years. The strip transect method was used (Caughley 1977; Eberhardt et al. 1979).

The northern end of each survey transect was designated as a 9/10 concentration of pack-ice. Prior to each survey, the approximate location of this edge was determined on the basis of information provided by the Atmospheric Environment Service (AES) ice reconnaissance team based in Inuvik, NWT, and the AES Beaufort Weather and Ice Office in Tuktoyaktuk, NWT. Because the pack-ice edge was unconsolidated during July and August, most northbound transects ended over a 7/10 or 8/10 concentration of pack-ice. The permanent polar pack (ice concentrations of 9/10 or greater) was beyond the range of the aircraft. The pack-ice edge was also relatively unconsolidated during the September survey, but

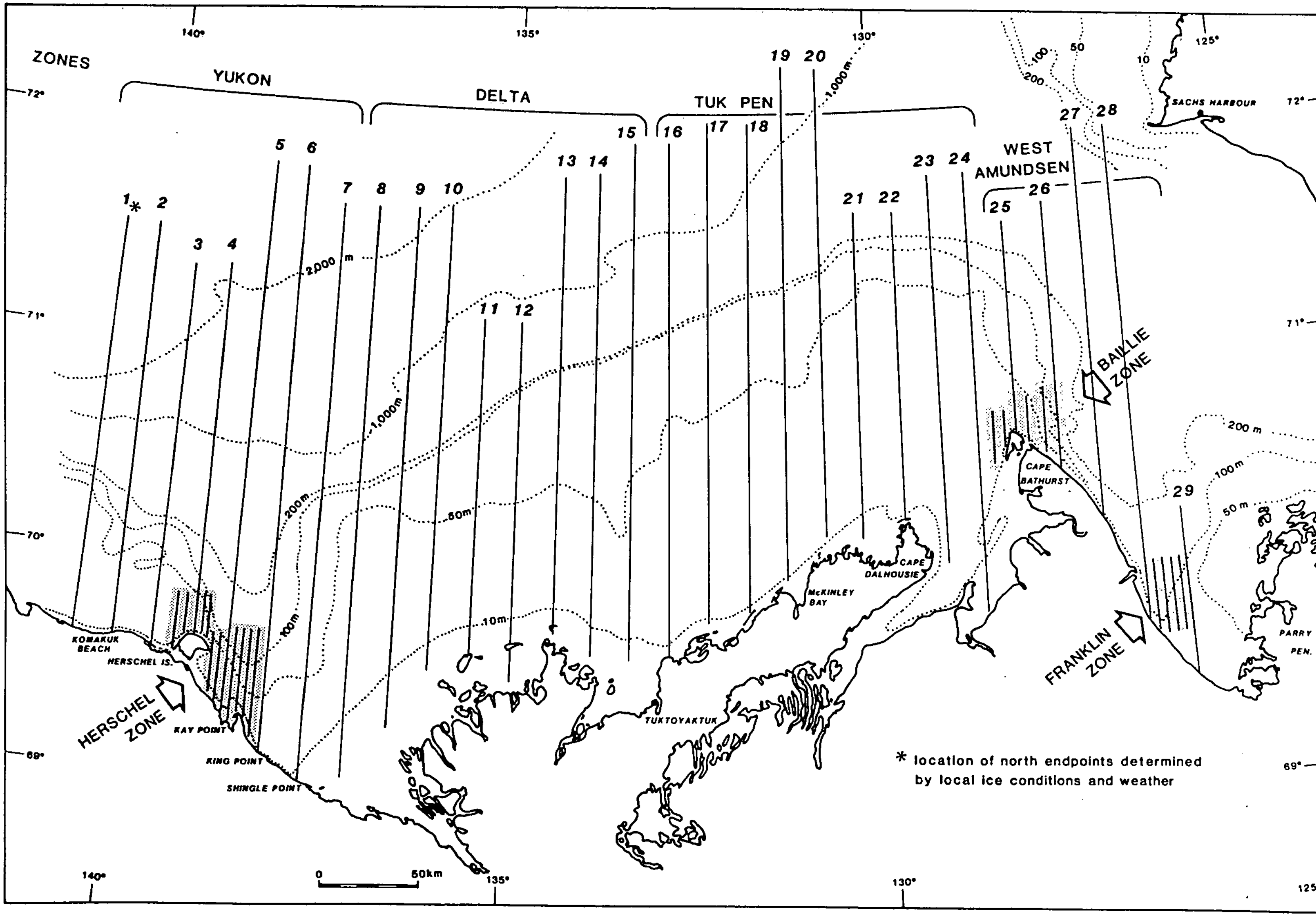


Figure 2. Location of 1984 bowhead systematic survey transects (August and September maximums combined).

the water between ice floes was frozen at the north end of transects. As a result, ice concentrations of 9/10 and 10/10 were surveyed.

One additional flight on 12 September 1984 was a 320-km^2 reconnaissance survey along a thermal front depicted in the satellite imagery.

Survey Procedures

The aerial surveys were conducted from two Series 300 de Havilland Twin Otters based in Inuvik, NWT. A pilot, co-pilot, and two observers were present in each aircraft during all flights. The aircraft were equipped with either a Global Navigation System (GNS-500) or a Collins LRN-70 system. When weather permitted, the two aircraft were operated simultaneously on adjacent pairs of transects. Radio communication between survey personnel in both planes was maintained to allow exchange of information on sightings, weather, and flight plans.

A survey altitude of 305 m (1000 ft) was planned for all surveys, and achieved for 92.5 per cent of the total transect distance flown. Low-overcast conditions necessitated a survey altitude of 152 m for the remaining transect distance. Survey altitudes were checked and maintained with radar altimeters.

The planned ground speed of the aircraft was 200 km/h (108 knots) during surveys of transects, and 278 km/h (150 knots) during ferrying flights and flights between transects. The calculated mean ground speed was 194 km/h during the transect surveys, but the mean ground speeds for the various transects ranged from 161 km/h to 218 km/h because of the effects of wind.

The left side observers on the two aircraft occupied the second rear seat behind the pilot, and surveyed through a bubble window. The right side observers occupied the co-pilot's seat. This configuration was used to be consistent with past surveys in the region and to take advantage of the better forward visibility from the co-pilot's seat. Communication between observers and pilot was maintained using an intercom.

Surveys either were not attempted or were terminated if there was cloud below 152 m, if there was surface fog, or if the sea state exceeded 5 on the Beaufort Scale of Wind Force. However, if survey conditions were less than adequate in only limited areas of a transect, the flight was continued, but surveying discontinued, until conditions returned to adequate. Portions of transect lines with less than adequate survey conditions are indicated on the bowhead distribution maps with a dashed line.

Observers recorded information on all marine mammals (including polar bears) sighted on- and off-survey transects and during ferrying flights. The observations were recorded on audio cassette tapes and later were transcribed to data sheets. Whenever possible, information recorded for each sighting included:

- species
- number of individuals
- time and location of sighting
- inclinometer reading (see below)
- physical habitat associations (e.g., ice, sea state, water colour)
- age (calf vs. adult on basis of size and colour)
- distance between individuals and group organization
- behaviour
- direction and rate of movement with respect to compass headings and geographic features
- presence of seabirds, mud trails, etc.
- sighting cue
- proximity to geographic features
- unusual markings or distinguishing features.

The distance of a marine mammal from the centre line of the transect (flight path) was estimated with Suunto PM-5/360 S inclinometers. The inclinometer was used to measure the angle of depression from horizontal of an animal when it was abeam of the aircraft. The lateral distance between the animal and the aircraft was subsequently calculated on the basis of this angle and the survey altitude. This method was also used in previous years (Davis et al. 1982; Harwood and Ford 1983; McLaren and Davis 1985).

A "group" of bowhead whales was defined as two or more whales within close physical proximity (<5 whale lengths), or two or more whales moving in the same direction or engaged in the same apparent activity within about 500 m of each other. A group of whales or a solitary whale constituted a "sighting".

In the present study, a transect width of 2 km (1 km on either side of the aircraft) was planned and adopted (see Appendix 3). At the survey altitude of 305 m, the transect strip extended from 50 m to 1050 m from the flight path on the left side of the aircraft, and from 150 m to 1150 m on the right. At the lower survey altitude of 152 m, the 2-km wide transect strip was 25 m closer to the flight path.

The geographic location of each sighting was recorded as the distance from the end of the transect, as indicated by the navigation system of the survey aircraft. Synchronized digital watches were used to record the start and end times for each transect and the time of each sighting. This information, along with mean ground speed, served as a check and back-up in plotting the locations of sightings.

During all surveys, each observer separately recorded information on weather (wind, fog, precipitation), wave direction, the location of any visible fronts or accumulations of debris, sea state, and concentration and type of ice. Survey conditions were assessed continually and independently by each observer. Observers also routinely recorded water colour in five broad categories (blue-black, blue-green, green, green-brown, and muddy brown) using paper colour standards as a reference. Although this technique is subjective, the patterns of water colour noted by observers are a useful substitute for turbidity data in areas where cloud obscured the sea surface during the satellite pass.

Data Analysis

Bowhead densities were calculated on the basis of the transect strip area surveyed, and then extrapolated to unsurveyed portions of the study area to provide estimates of relative bowhead abundance. Off-transect and ferrying sightings provided additional information on behaviour of bowheads and general patterns of distribution.

To arrive at approximate estimates of actual abundance, these estimates were corrected for surfaced but undetected bowheads and for submerged bowheads. Correction factors specific to the 1984 surveys could not be calculated from the type of data collected, so correction factors calculated by others in past years were used. During 1981 surveys, Davis et al. (1982) estimated that observers missed 31.5 per cent of surfaced bowheads, and that bowheads were visible at the water surface 26.1 per cent of the time. Wursig et al. (1984a) estimated that the mean time whales (excluding calves) were visible from the air was 24 per cent in 1982 and 41 per cent in 1983 (35 per cent excluding whales that were skim-feeding). The correction factors used for the present study were broadly and conservatively set on the basis of the range of mean values calculated during the above studies, and assume the following:

- observers miss 30 to 35 per cent of surfaced bowheads (uncorrected counts multiplied by 1.43 and 1.54); and

- bowheads are visible at the surface 25 to 40 per cent of the time (uncorrected counts multiplied by 4.0 and 2.5).

AERIAL SURVEYS -- JULY TO EARLY AUGUST

As indicated earlier, the present report also includes bowhead sightings from the July to early August offshore white whale program. The study area in these surveys extended from longitude 141°W (Alaska-Yukon border) to longitude 127°50'W (Baillie Islands), and from the mainland coast seaward to a 7-9/10 concentration of pack-ice.

The surveys in this study were designed to examine white whale distribution, and for this reason, extended shoreward into shallower waters than could be used by bowhead whales. For the purpose of the present analyses, however, the shoreward boundary has been adjusted to include only those waters deeper than 2 m. The geographic location of the seaward boundary of the study area varied between surveys, but was a 7-9/10 concentration of pack-ice during each program.

Survey transects for the white whale program were spaced at intervals of 16 km and 32 km, and the surveys were flown at the following times:

Survey 1	July 5, 6, 9
Survey 2	July 13, 17, 18
Survey 3	July 21, 22, 23
Survey 4	July 28, 30, August 2.

The methods and study approach used in the white whale program were the same as those used for the bowhead program with the following exceptions:

- one Twin Otter aircraft was used
- observers had identical seat positions on either side of the aircraft and both used bubble windows
- sampling intensity ranged from 3.2 to 9.7 per cent.

The same two observers conducted surveys during both the white whale and bowhead studies, although an additional four observers were involved in the latter.

LIMITATIONS OF SURVEY METHOD

It was beyond the scope of the present investigation to examine and correct for the various limitations associated with systematic aerial surveys of marine mammals. During the course of the surveys, there were specific situations where survey results could have been biased. Areas of potential bias have been identified throughout the discussion of 1984 results, and the resultant limitations considered during the interpretation of such data. Systematic surveys are an appropriate technique for a study with the dual objectives of mapping distribution and estimating abundance (Caughley 1977). As long as the results are interpreted in the broad sense intended, a study of this type provides an indication of relative patterns in abundance and distribution.

In the conduct of an aerial survey study, weather has a major role in determining survey timing and progression. Although it is desirable to survey the study area on consecutive days and follow a consistent transect-by-transect progression, it is also important to maximize the number of surfaced animals detected by observers.

Therefore, survey flights were attempted only when and where survey conditions were adequate, which occasionally affected survey timing and progression. Depending on the direction and rate of bowhead movements, interruptions in the timing and progression of surveys could have resulted in double-counting or missing some individuals.

Several factors associated with the visual survey method employed for this study can also introduce biases. Besides weather and survey conditions, the visual acuity, experience, and seat position of observers may influence results (Davis et al. 1982). Furthermore, the detectability of whales varies with sea state, with concentration of ice (Davis et al. 1982), and possibly with water colour. However, the visual method is used because it has a real-time observation period, and because a relatively large area can be searched within seconds (i.e., ~4 km^2 on-transect, and up to several km^2 off-transect depending on sea state).

Because the search time associated with the visual survey technique is limited, an assessment of the number of animals in a particular group cannot be made confidently. For example, whales in groups are probably more easily detected than solitary whales, yet at the same time, the number of whales in a group may be underestimated. Estimation is further complicated because the behaviour of whales probably changes diurnally and from one survey period to another (e.g., tendency to travel in groups is apparently greater during August and September than in July). Also, some groups may spend proportionately less time at the surface (e.g., those with calves) than others, and therefore have a lower probability of being detected.

MARINE MAMMALS REPORTED BY INDUSTRY AND SUPPORT PERSONNEL

Information describing bowheads, seals, and polar bears sighted by industry and support personnel in the southeast Beaufort region from June to October 1984 was provided by Dome Petroleum Limited and Esso Resources Canada Limited. (Whale sightings by Gulf Canada Resources personnel were included with those provided by Esso.) Data from these two sources were cross-checked to delete duplicate reports, and then were combined for discussion in this report. A brief description of the nature and origin of the two data sets follows.

Ice observers stationed on drillships operated by, or on behalf of, Dome recorded, whenever possible, wildlife sightings during a ten-minute observation period once every three hours. These reports include sightings made by ice observers during, and incidentally to, the designated wildlife watch periods. In addition, sightings of wildlife were recorded by other industry personnel on these drillships and on the various support vessels. Bowhead sightings were reported in 1984 by personnel on two drillships, two icebreakers, three supply vessels, and four support vessels.

Esso uses a different wildlife reporting scheme from Dome. At the beginning of each drilling season, sighting cards are distributed to Esso's facilities, vessels, and subcontractors, and to other vessels operating in the region. Anyone sighting a whale was asked to fill out a card, and send it to Esso's Calgary office. During 1984, personnel on one icebreaker, three supply vessels, one crew vessel, one tug, two dredges, and five helicopter flights, sent in cards describing bowhead whale sightings.

COINCIDENT SATELLITE IMAGERY

Sea surface temperature and turbidity were chosen as oceanographic indices in this study, first, because these two parameters can be measured easily and repetitively over large areas using satellite imagery, and secondly, because these parameters can be used as indicators of physical circulation, stratification, and heterogeneity. The most important physical oceanographic variables are temperature and salinity, which in the Beaufort are grossly affected by the input of warm, fresh water by the Mackenzie River (Herlinveaux and de Lange Boom 1975; MacNeill and Garett 1975; Grainger 1975). Temporal variation of the distribution of surface temperature and salinity in the Beaufort Sea is largely controlled by the wind regime. Under westerly or northwesterly winds, the surface water and pack-ice are pushed to the right of the wind with the result that there is an onshore movement of water and ice, and the open water zone decreases in size. The less dense river water is also affected by the Coriolos force that reinforces the wind-induced drift, with the net result that the river plume is pushed against the coast with a relatively contained distribution. Surface drift under easterly winds is away from the coast, resulting in an increase in the open water area. Because the offshore push of an easterly wind acts in oppostion to the Coriolis force, the less dense river water is driven much further offshore during this wind regime. Prolonged periods of easterly wind will direct the plume along the Yukon coast (Herlinveaux and de Lange Boom 1975; MacNeill and Garett 1975). Because the distribution of the less dense river water spreading out over the southeast Beaufort Sea is largely controlled by the wind, considerable geographic variation in the distribution of the river plume is seen (MacNeill and Garett 1975; Borstad 1985a).

Repeating observations that had been made more conventionally elsewhere (e.g., Nasu 1966 in Gaskin 1976), Borstad (1985a) showed that bowhead whales congregate near oceanographic discontinuities such as fronts, eddies, and upwellings that can be seen in satellite imagery.

The reason for this probably relates to a local abundance of food organisms (zooplankton) at these types of physical phenomena (Pingree et al. 1974; Floodgate et al. 1981; Hamner and Hauri 1981). However, satellite imagery cannot be used to detect or quantify zooplankton concentrations; in situ or acoustic sampling would be required.

Data Reception

Digital data from the Advanced Very High Resolution Radiometer (AVHRR) on board the American satellite NOAA 7 was obtained during the August and September surveys from the Department of Oceanography at the University of British Columbia. For three days prior to, and during, each survey period, data from a minimum of one pass per day over the south Beaufort (usually an ascending pass between 1500 and 1630 h PST) was acquired and the image was examined for cloud cover. If a portion of the study area was cloud-free, the University of British Columbia (UBC) operator copied it to computer-compatible magnetic tape and sent the data by courier to Sidney, B.C., for analysis. Useful cloud-free images were obtained for 22 August and 8, 11, and 12 September 1984. Digital images for the month of July were obtained from the AES in Edmonton as part of a separate project (Borstad 1985b).

Processing and Calibration of Images

Digital AVHRR images from bands 1 and 4 (0.55-0.90 μm in the visible and 10.3-11.3 μm in the thermal infrared) were processed using the facilities of the Institute of Ocean Sciences image processing laboratory in Sidney, B.C. Each image was first examined on the video display screen before a subset of cloud-free data over the study area was selected for further processing. Geometric distortions in the imagery, caused by the earth's curvature, satellite motion, and the sensor scanning mechanisms, were corrected using processing procedures that require the operator to match recognizable topographic features in the image to their location on a digital atlas map accessed by the computer. Beginning with approximate orbital parameters (such as satellite altitude, distance along the orbit, and scan angle) and known latitude and longitude of several points within the image, the program calculates the exact orbital parameters (and therefore the geometry for every point in the image) by successive iteration. The corrected image data were then replotted to fit an equi-rectangular projection (a simple Mercator-like projection in which the meridians of longitude and lines of latitude are equidistant and parallel) with a geometric accuracy better than 2 km everywhere in the image.

The rectified band 4 (thermal) and band 1 (visible) data were then "masked"[1] for cloud and ice by relying on the fact that both cloud and ice are colder and brighter than water features in the area. Although the pack-ice edge can be identified through some types of thin cloud, our current procedures do not allow consistent, unambiguous separation using digital techniques. Consequently, cloud and ice features were not differentiated for the images presented here. Where spatial pattern, and texture, or both allowed a separation, the appropriate areas have been labelled. To facilitate analysis of the data, the coastline, latitude and longitude, and survey flight lines were also added to each image.

Sea surface temperature and turbidity patterns in open water areas were determined from analysis of the thermal and visible bands, respectively. The images presented in this report (see plates 1, 2, 3, and 4) have been "contrast stretched"[2] to improve the contrast in both temperature and turbidity patterns.

An approximate calibration of the band 4 thermal imagery was possible using in situ sea surface temperatures recorded at the industrial drillships as part of their hourly weather observation program. The technique used was a simple "field calibration" essentially after Tabata and Gower (1980), who found that the AVHRR band 4 digital levels are linear with sea surface temperatures with a fairly constant offset. Figure 3 illustrates the relationship for the few in situ temperatures available for the 22 August and 11 September images. Because there may be a positioning error of 1-2 km in the geometric correction of the imagery, the range of digital levels within 2-3 km of the position of each vessel has been plotted as a vertical error bar. Hourly fluctuations recorded one hour before and after the time of the satellite pass are shown as horizontal error bars. An approximate field calibration line has been drawn through these error bars, placing most

---

1 Masking is an image analysis procedure in which an area (or areas) in a digital image is assigned a uniform value, colour, or grey level for presentation to visually set that area off from others. In Plates 1, 2, 3, and 4 (pages 45, 46, 50, and 51), cloud and ice are white, land is black.

2 Contrast stretching implies that the colours assigned to the digital range of the sensor (1 to 256 here) have been altered so as to magnify the colour differences between adjacent levels. The colour bar on the bottom of each image indicates what enhancement has been applied. A colour bar with black at the extreme left (digital value 0) and white at the extreme right (digital value 255) would indicate no enhancement.

reliance upon the points having the smallest variability in space and time. The small number of points and the temporal and spatial variability does not allow a calibration more accurate than $\pm 1^{\circ}C$. Quantitative calibration of the band 1 visible images in terms of milligrams of suspended material per cubic metre was not possible because in situ data were not available.

Transmission of Imagery to Field Crew

Paper copies of the completed analyses were transmitted from Sidney, B.C., to the field crew in Inuvik in the form of contour charts of water colour and temperature patterns. Each chart depicted these patterns in a range of four to five intervals derived from the digital image analyses.

The charts were printed in Sidney on a dot-matrix printer at two scales. A small-scale chart provided an overview of the available data for the study area, whereas an enlarged version was used to highlight specific areas related to survey flight lines. Completed charts were transmitted to Inuvik along normal voice-grade telephone lines using Burroughs DEX 1100 portable telecopiers. The charts from the previous day's image were available for review by the field crew prior to the start of each day's survey. Examples of transmitted charts are provided in Appendix 5.

LIMITATIONS OF SATELLITE IMAGERY

Although there are considerable advantages to the use of satellite data in remote areas such as the Beaufort (e.g., large areas are viewed repetitively and instantaneously), certain limitations to this method should be recognized.

a) Only the uppermost surface layer is measured (about 50 μm in the case of the thermal infrared, and for the range of suspended materials in the Beaufort, between about 5-6 m and a few centimetres for the visible band).

b) In situ data are required for calibration of remotely sensed data because a number of phenomena can alter the relationship between the signal seen at spacecraft altitude and the in situ variable.

c) Both temperature and turbidity measures require a clear view of the sea from the spacecraft (e.g., thermal and visible imagery cannot be obtained through cloud).

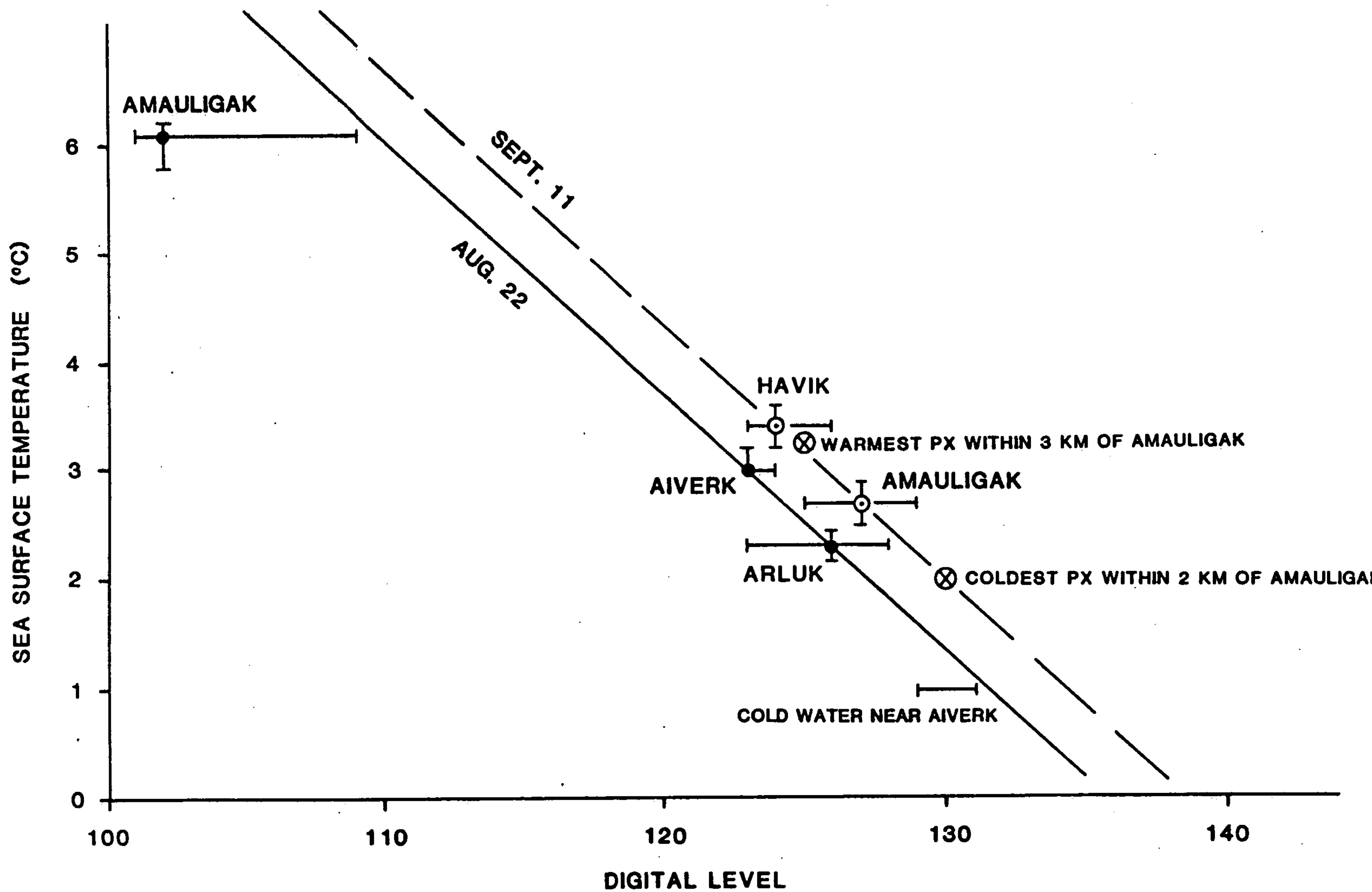


Figure 3. Calibration for 22 August and 11 September 1984 thermal images.

In spite of these limitations, useful imagery can be obtained for the Beaufort and other parts of the Arctic. Except in small, strongly stratified bays and inlets well protected from the wind, or in conditions of no wind, the temperature of the surface skin is very nearly equal that of the top 1-3 m (Robinson et al. 1984). When sufficient coincident in situ data are available for cloud-free parts of an image, simple linear relationships can be obtained between the uncalibrated thermal band 4 AVHRR data and sea surface temperature ($\pm 0.5^{\circ}C$, Tabata and Gower 1980; Borstad 1985a) and between AVHRR band 1 and the weight of surface suspended material (± 2 mg/L, Borstad 1985a). These relationships apply over a few hundred kilometres within any particular image, but because the spacecraft sensor detects the sum of the signal from the sea and that from the atmosphere, they change with varying seasonal illumination and atmospheric absorption and scattering (with spatial scales equal to meteorological events).

For the work reported here, only a few in situ temperature data were available for each image. The authors therefore show uncalibrated imagery, but have added an approximate calibration scale to the thermal imagery. Excluded from the analysis are those areas affected by cloud, fog, or mist; the remaining signals and patterns are from the water itself and represent the content of suspended material near the surface. Following McClueny (1975), the term "turbidity" is used in a qualitative sense to refer to the uncalibrated band 1 data because it is essentially a visual estimate of water clarity.

RESULTS

The results of the 1984 systematic aerial surveys of bowhead whales in the southeast Beaufort Sea are described in the remainder of this report. Information on ringed seals (*Phoca hispida*), bearded seals (*Erignathus barbatus*), walruses (*Odebenus rosmarus*), and polar bears (*Ursus maritimus*) collected during the course of the bowhead surveys and by industry personnel is presented in Appendices 5 and 6. Data on the distribution and abundance of white whales (*Delphinapterus leucas*) collected during the bowhead surveys in late August and September are discussed in Norton and Harwood (1985).

AERIAL SURVEY RESULTS

Chronological Summary of Bowhead Distribution, Movements, Behaviour, and Relative Abundance

The location of each bowhead sighted during the six systematic aerial surveys from July through September is provided in this section, along with information on the observed direction of bowhead movement, coincident ice conditions, and sites of stationary industrial activity. The locations of bowheads observed on ferrying flights and on a reconnaissance flight are shown separately.

First half of July 1984. Two systematic surveys were conducted during the first half of July 1984 (Figures 4 and 5). Three bowheads (two sightings) were observed on-transect during these two surveys; no calves were recorded. One additional bowhead was seen during a ferrying flight on 5 July. These whales were observed in three different habitats (ice-free/ nearshore, 1-3/10 ice, and 7-9/10 ice), and in two zones (Yukon and Tuk. Pen.).

Although sample size and survey sequence and timing preclude statistical analysis of this data, bowheads were apparently not present in large numbers (i.e., probably <300), in the southeast Beaufort during the first half of July 1984.

Third week of July 1984. The third systematic aerial survey of the region was conducted on 21, 22, and 23 July 1984. Because of favourable weather, this survey was completed within 48 h and in the planned west to east progression.

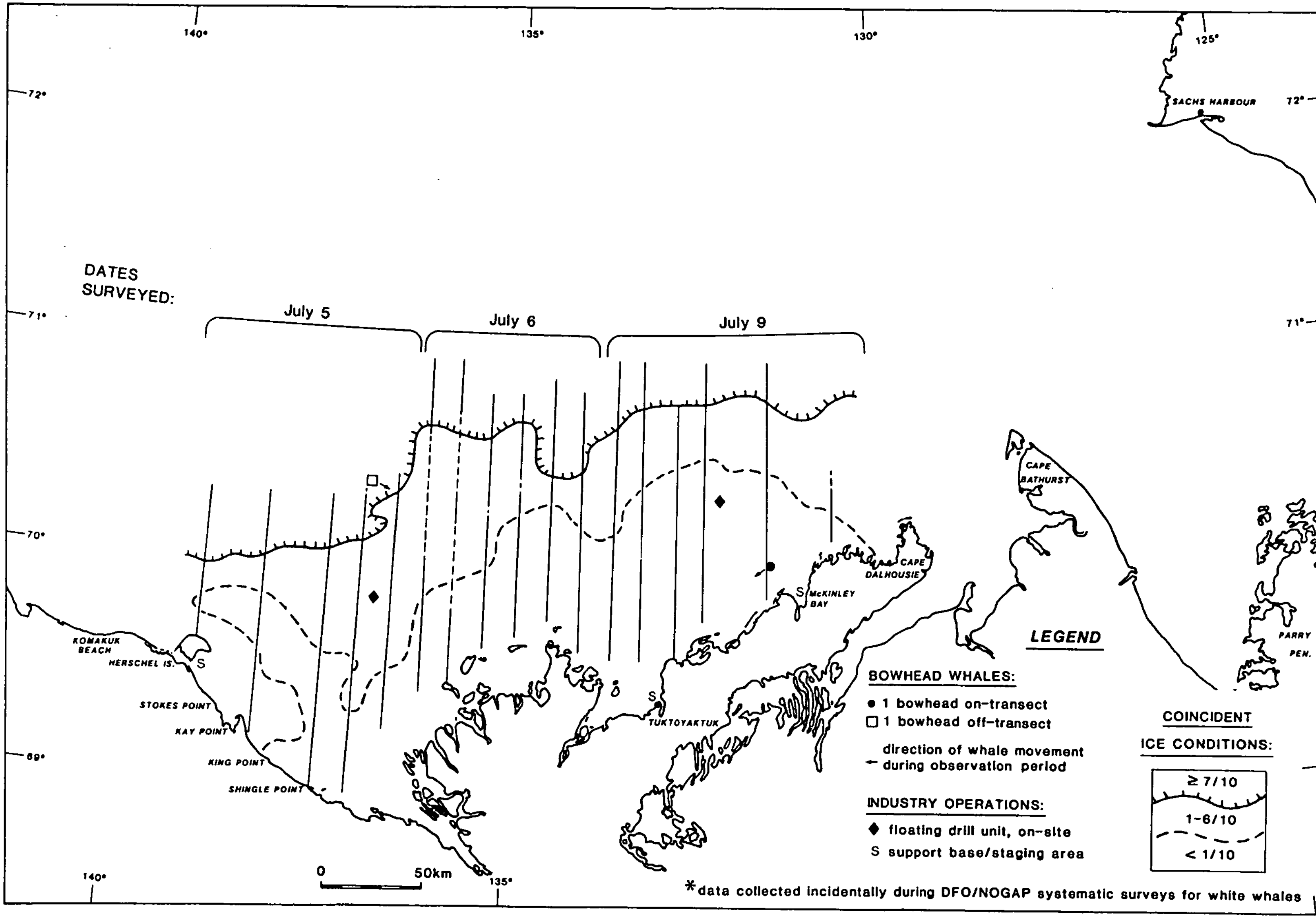


Figure 4. Bowhead whale sightings -- systematic survey,* 5-9 July 1984.

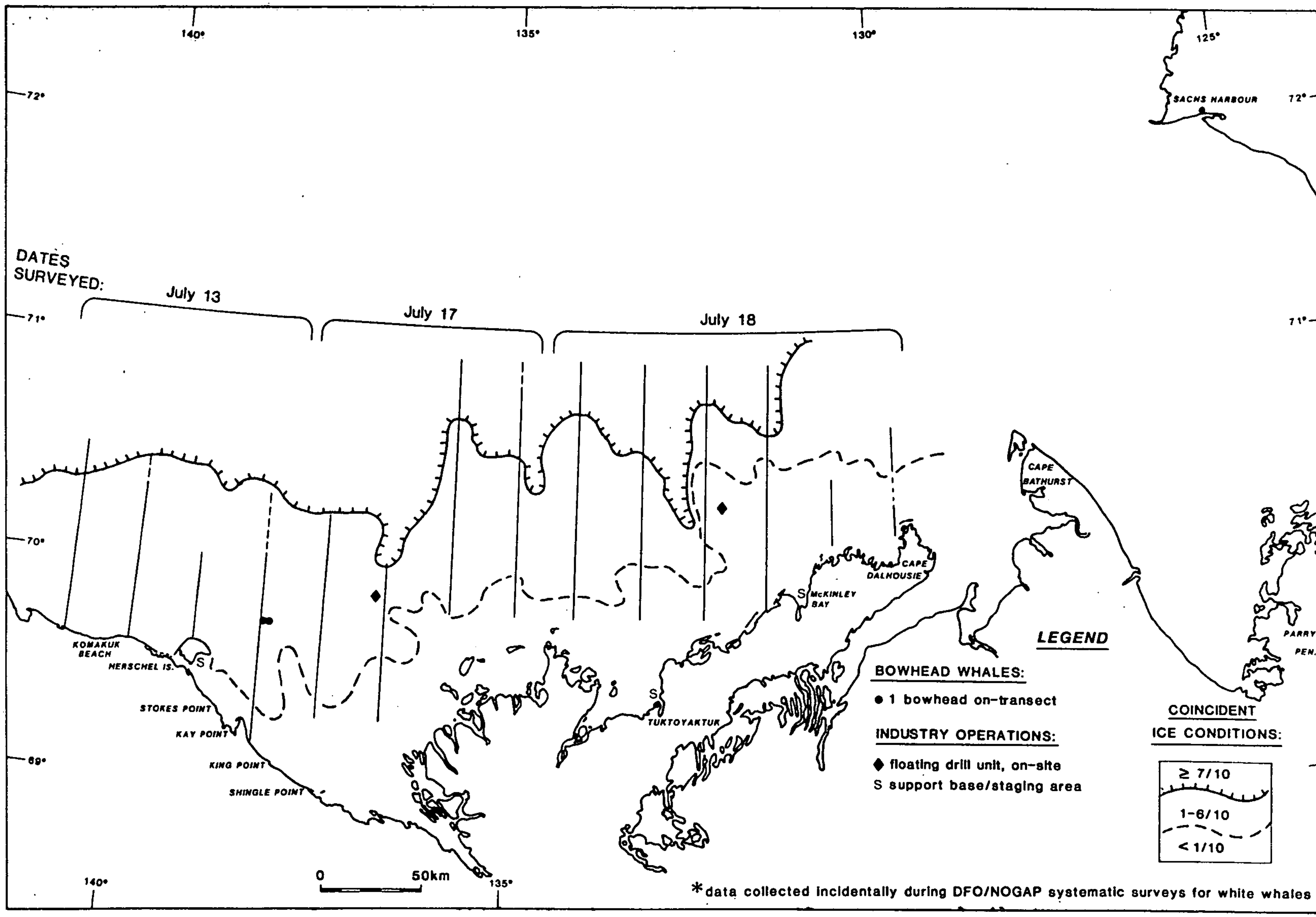


Figure 5. Bowhead whale sightings -- systematic survey,* 13-18 July 1984.

Fifteen bowheads (13 sightings) were seen on-transect during this survey, and an additional seven were seen during the ferrying flights (Figure 6). No calves were observed. During this survey, bowheads were apparently more abundant than in the first half of July. An estimated 900-1500 bowheads were present in the study area.

Bowheads were observed in all zones within the study area, but were concentrated in two areas, one located east of Herschel Island and the other near Baillie Islands (see Figure 6). Most of the whales were observed in clear marine waters where the ice concentration was <1/10. One whale was noted in relatively turbid water on the Tuk. Shelf, and two solitary bowheads were observed lying motionless at the surface among 7-9/10 concentration ice. All bowheads sighted during this survey were either diving, resting, or swimming at the surface. Most whales exhibited directional movement during the observation period (Figure 7), but no direction was predominant.

End of July and early August 1984. The fourth survey in this sequence was the final one completed in the offshore white whale program (Figure 8), and was conducted from 28 July to 2 August 1984. During this survey, coverage of the Delta Zone was incomplete, and survey timing and progression were interrupted.

Seven bowheads (six sightings) were seen on-transect and two were seen off-transect. As in the previous surveys, no calves were observed. An estimated 800-1500 bowheads were present in the study area during this survey.

Bowheads were observed about 100 km off the Tuktoyaktuk Peninsula and 100 to 200 km off the Yukon coast (see Figure 8). Most whales were moving during the observation period, although there was no predominant direction of movement. One solitary adult was stationary at the surface in <1/10 ice, whereas most others were observed moving among ice ranging from <1/10 to 2/10. Bowhead behaviour recorded during this survey included diving, resting, and swimming at the surface.

Late August 1984. This survey was the first of two conducted specifically for ESRF and INAC to examine the distribution of bowheads in the southeast Beaufort Sea, and was completed from 18-27 August 1984. Thirty-six bowheads (33 sightings including one unconfirmed calf) were seen on-transect, 17 (14 sightings) were seen off-transect, and 41 (including 1 calf) were seen during ferrying flights. An estimated 800-1200 bowheads were present in the study area during this survey. With the exception of the western portion of the study area, survey progression and timing were not seriously disrupted by adverse weather (Figure 9).

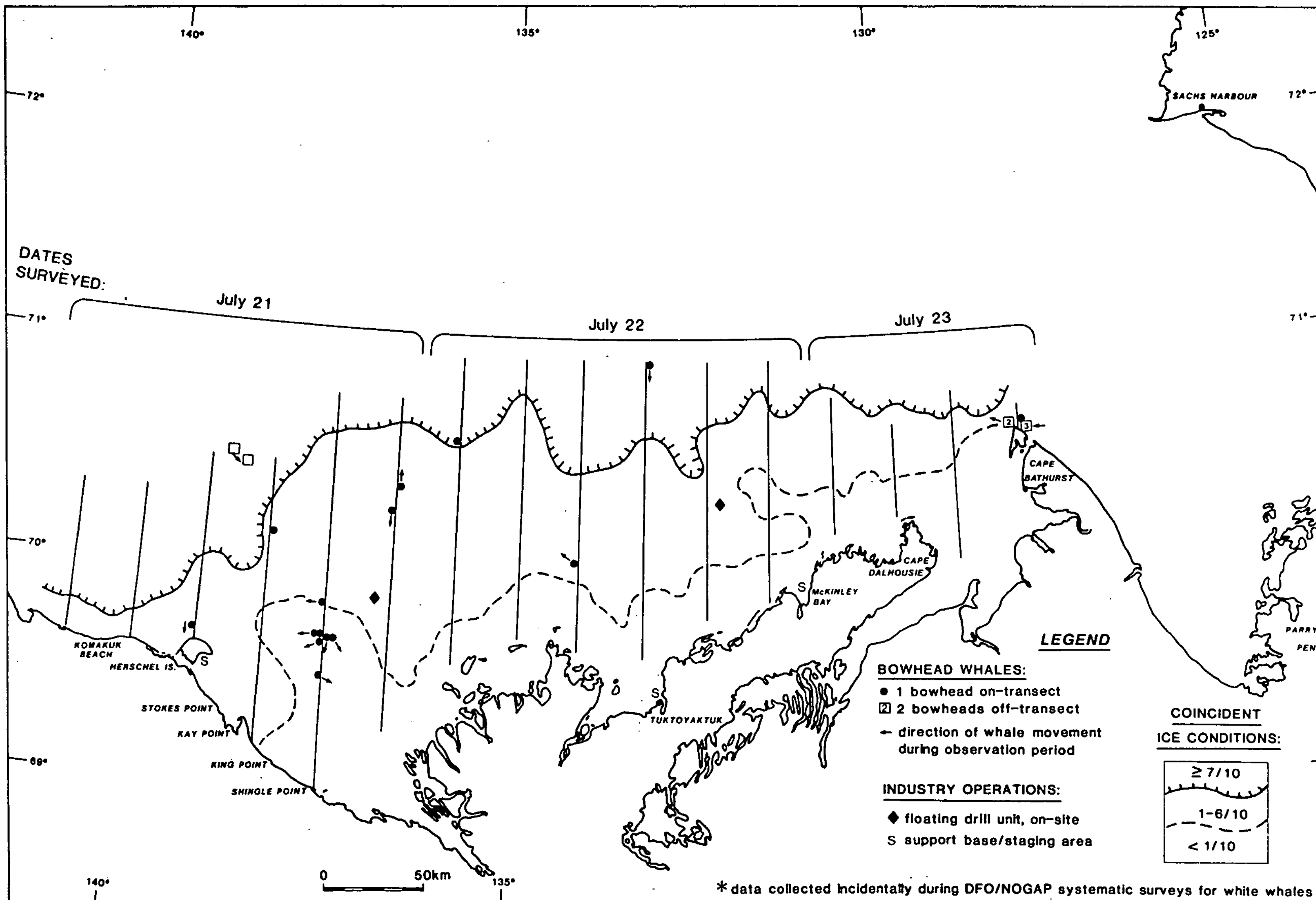


Figure 6. Bowhead whale sightings -- systematic survey,* 21-23 July 1984.

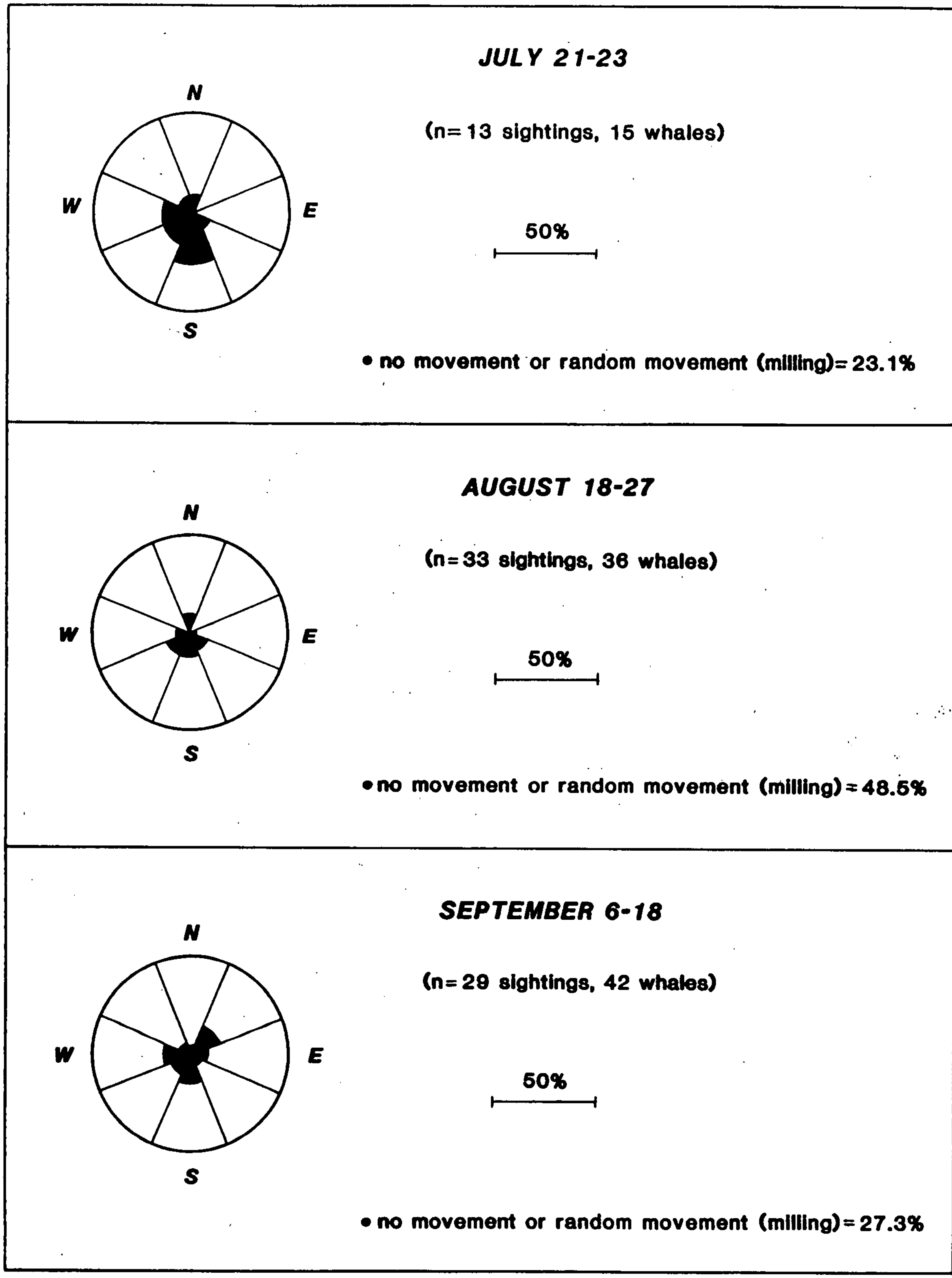


Figure 7. Observed direction of bowhead whale movement, July-September 1984 (per cent of total on-transect sightings).

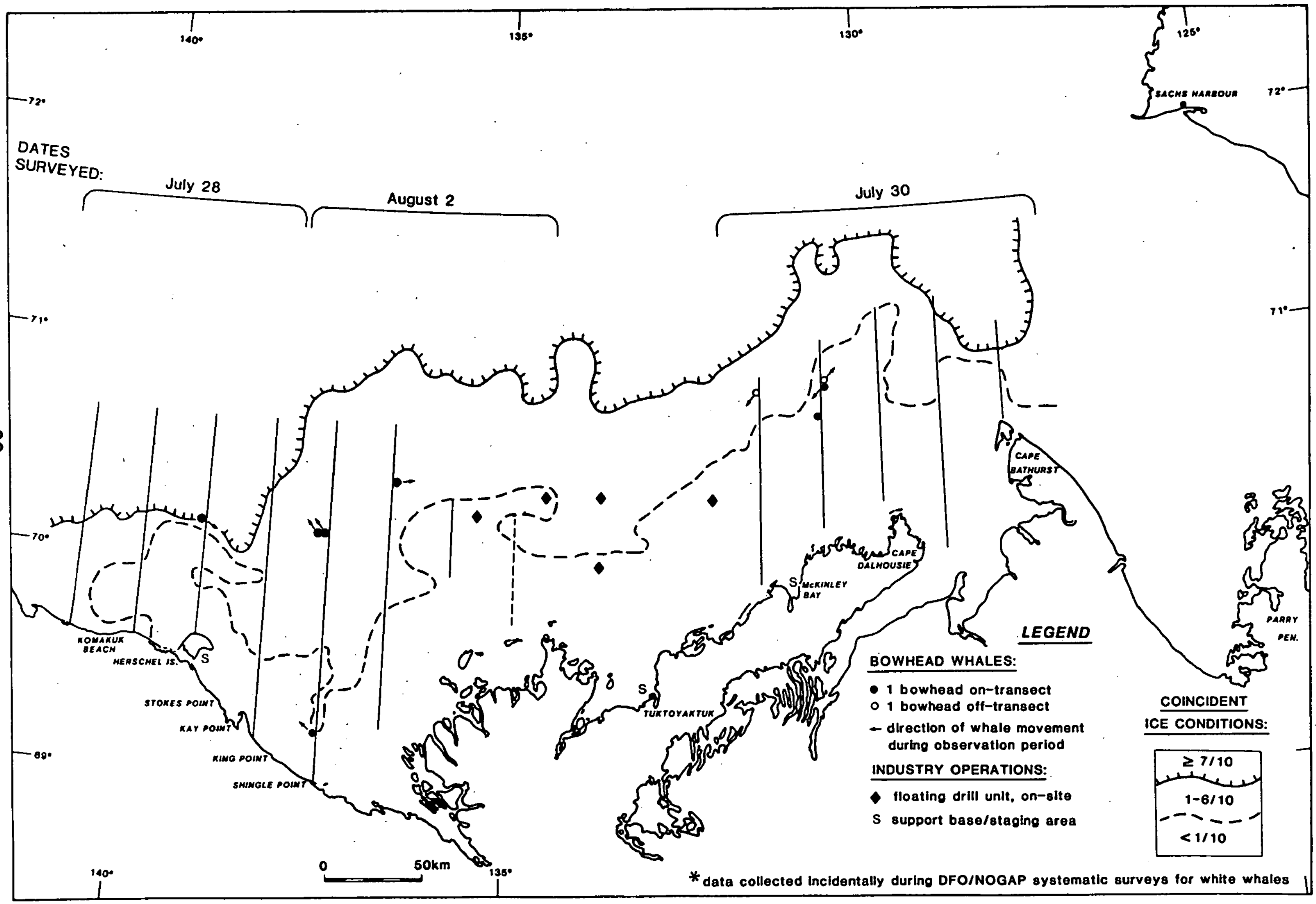


Figure 8. Bowhead whale sightings -- systematic surveys,* 28 July-2 August 1984.

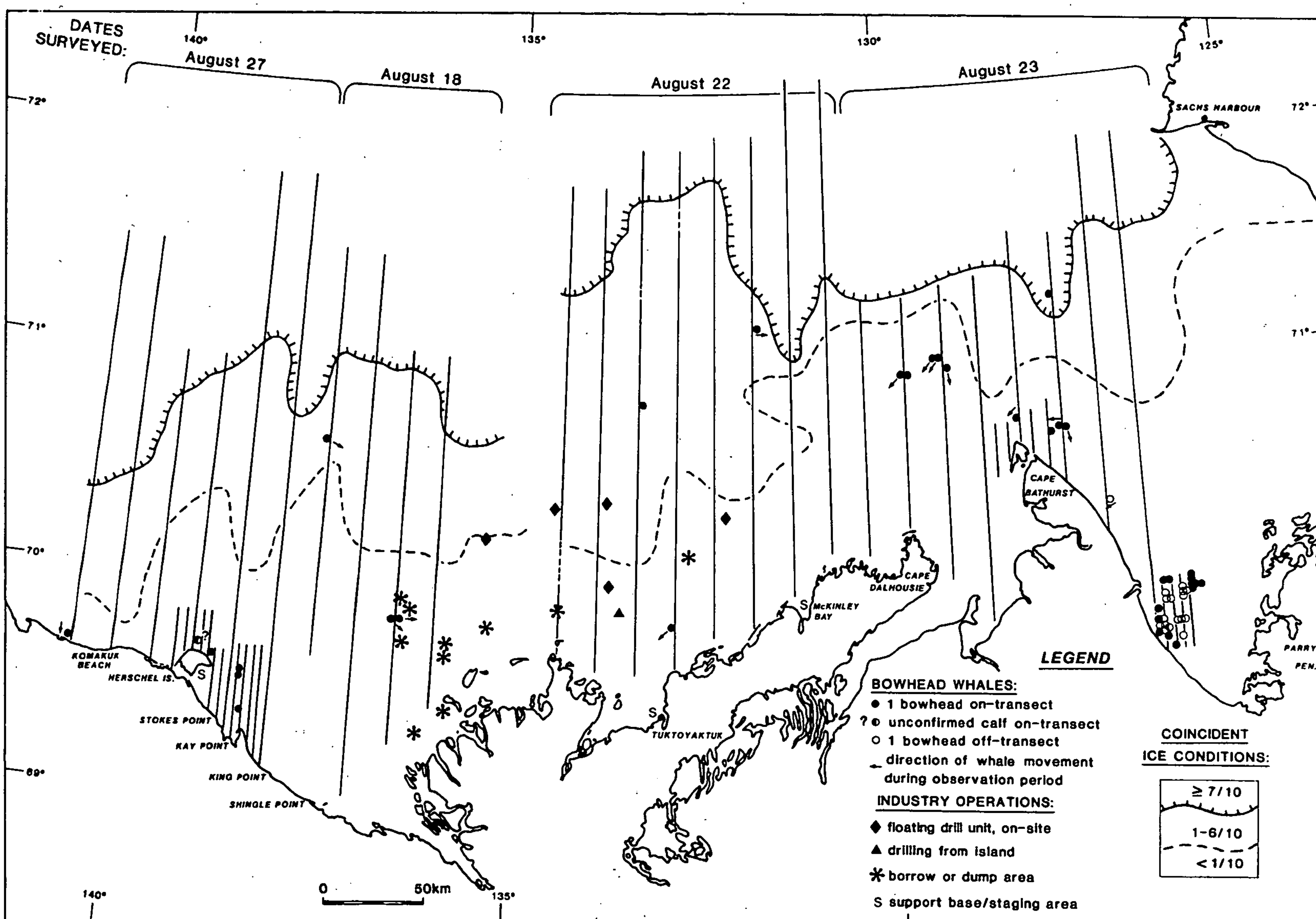


Figure 9. Bowhead whale sightings -- systematic surveys, 18-27 August 1984.

The most striking feature of bowhead distribution during late August was that the whales were congregated in several areas (see Figure 9), which was verified by sightings during ferrying flights (Figure 10). A small number of bowheads observed on-transect during the survey were not associated with the congregation areas noted during transect surveys and ferrying flights. In general, the behaviour and apparent activities of bowheads in areas of congregation were different from those of whales observed during July, and in other areas. The directions of whale movement are presented in Figure 7.

Congregations of bowheads seen on-transect were located:

- in Franklin Bay
- near Cape Bathurst
- offshore of Cape Dalhousie at about latitude 71°N
- along the Yukon coast between Kay Point and Herschel Island.

Two more bowheads were observed at the edge of the Mackenzie plume in an area where other researchers estimated that 15 to 25 whales had been present on previous days[1] (Davis et al. in prep; Richardson et al. MS). Other bowhead congregation areas were seen during the surveys, but, because of local whale movements or transect positioning, were not included in the systematic coverage. However, these areas were overflown when ferrying, and relatively large numbers of bowhead whales were seen (see Figure 10). These concentration areas included an area about 2 km west of Komakuk Beach, the north and northwest coasts of Herschel Island, and the Yukon coast between King Point and Shingle Point. Several bowheads observed near Komakuk and between King and Shingle points were within 100 m of the beach.

The amount of usage of congregation areas appeared to vary from day to day and among areas. Bowheads were sighted in some locations, such as along the coast of Herschel Island, whenever the area was overflown (twice during the survey in late August and four times during the September survey). In contrast, at other locations such as near Komakuk, bowhead congregations were observed on some days (e.g., 18 August) but not on others (e.g., 27 August).

The activities of bowheads recorded in the coastal congregation areas were generally similar to feeding and socializing behaviours described by Ljungblad et al. (1984) for bowheads in Alaskan waters. The following behaviour patterns were noted: milling (whales swimming slowly around each other at the water surface); physical interaction of cow-calf pair; displaying (rolling, flipper slapping); possible feeding (mud streaming from mouth); swimming slowly along the seaward edge of a surface discontinuity or front; and surface feeding (open-mouth surface swimming).

---

1 D. Rugh, pers. comm.

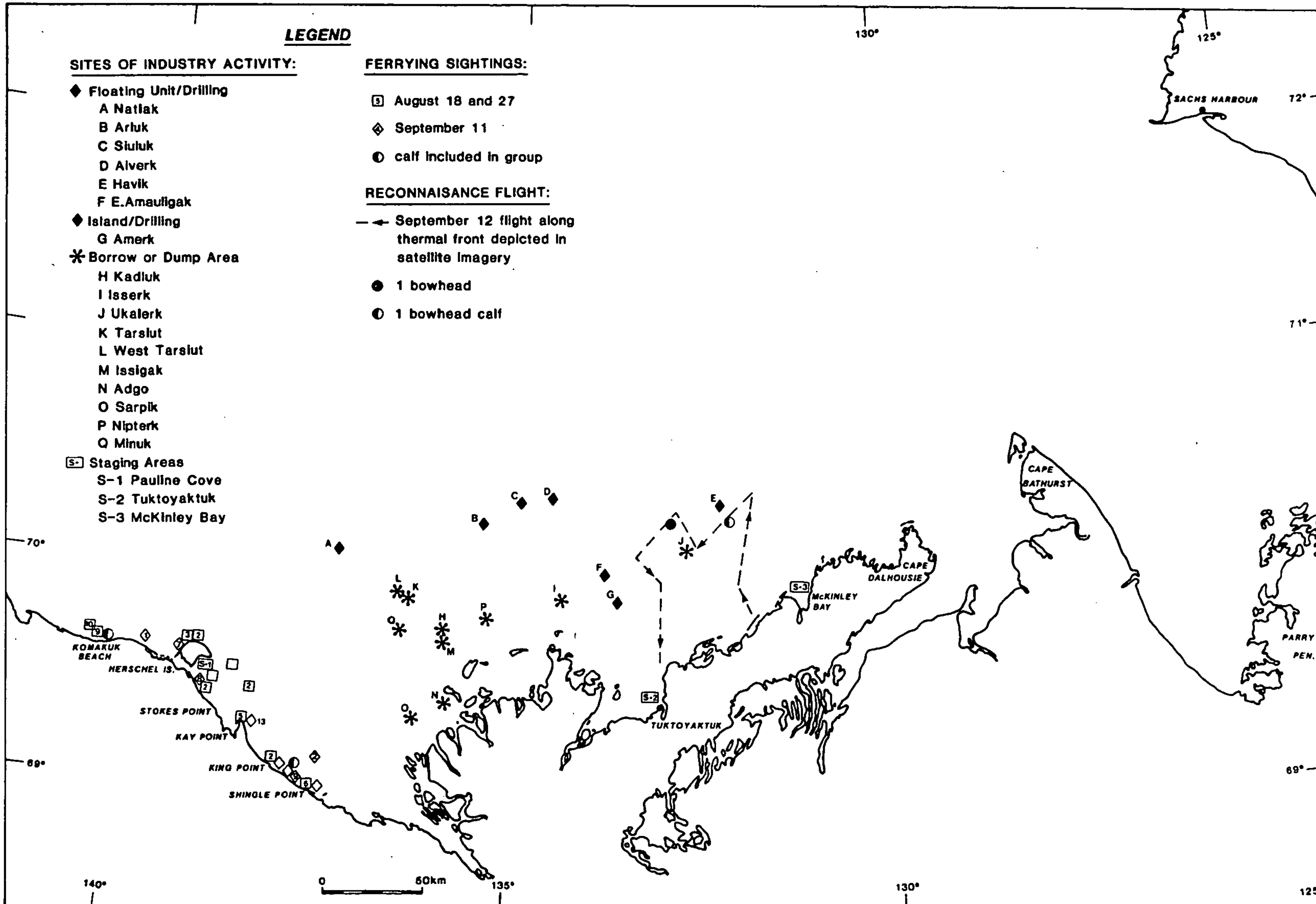


Figure 10. Sites of industrial activity and bowhead whales sighted during ferrying and reconnaissance flights, August-September 1984.

About 18 per cent of the on-transect bowhead sightings (six sightings) during the survey in late August were outside the congregation areas previously described. These animals were recorded in all zones and in both offshore (four whales) and coastal (two whales) waters. All were observed as solitary individuals and were within ice concentrations ranging from 1-7/10. Observed whale activities included swimming at the surface, diving, and resting. Three of these animals exhibited directional movement, but no direction was dominant (see Figure 7).

Because all whales within a group may not necessarily have been at the surface during the passage of the survey aircraft, these sightings may have included only a portion of a group. For example, on 22 August a solitary bowhead was observed about 20 km offshore of Toker Point. Another research team (Davis et al. in prep.) searched the area about 1.5 hours later and estimated that at least 15 bowheads were present. Therefore, it cannot be concluded that individuals noted as solitary were necessarily alone and in a "non-congregation" area.

September 1984. The final survey in the series was flown from 6 to 18 September 1984, and was most hampered by adverse weather. Both survey timing and progression were interrupted because of weather conditions (Figure 11).

Forty-two bowheads (29 sightings) were observed on-transect during this survey. An additional five were seen off-transect, and 66 (including one calf) were seen on ferrying flights. No calves were sighted on-transect in September. An estimated 1500 to 2400 bowheads were present in the study area during this survey.

As in late August, congregations of bowheads were common during September (see Figure 11). During the transect surveys, bowheads were found to be concentrated in Yukon coastal waters between Shingle Point and King Point, northeast of Kay Point at latitude 69°30'N, at the seaward edge of the Mackenzie River plume, the north and northwest coasts of Herschel Island, north of Cape Dalhousie, in the vicinity of latitude 71°N, and in the west Franklin Bay. In contrast to the survey in late August, ferrying flights in September did not observe the location of any additional bowhead congregations. A reconnaissance flight planned on the basis of satellite imagery located one adult and one calf on the Tuktoyaktuk Shelf.

The activities of bowheads observed in the congregation areas during September flights were similar to those of bowheads seen in these areas in late August. One additional display behaviour (breaching) was seen during September. As in the survey in late August, a small number of bowheads were seen as solitary individuals and were not near the congregation areas (see Figure 11). The observed direction of movement for each on-transect bowhead sighting is summarized on Figure 7.

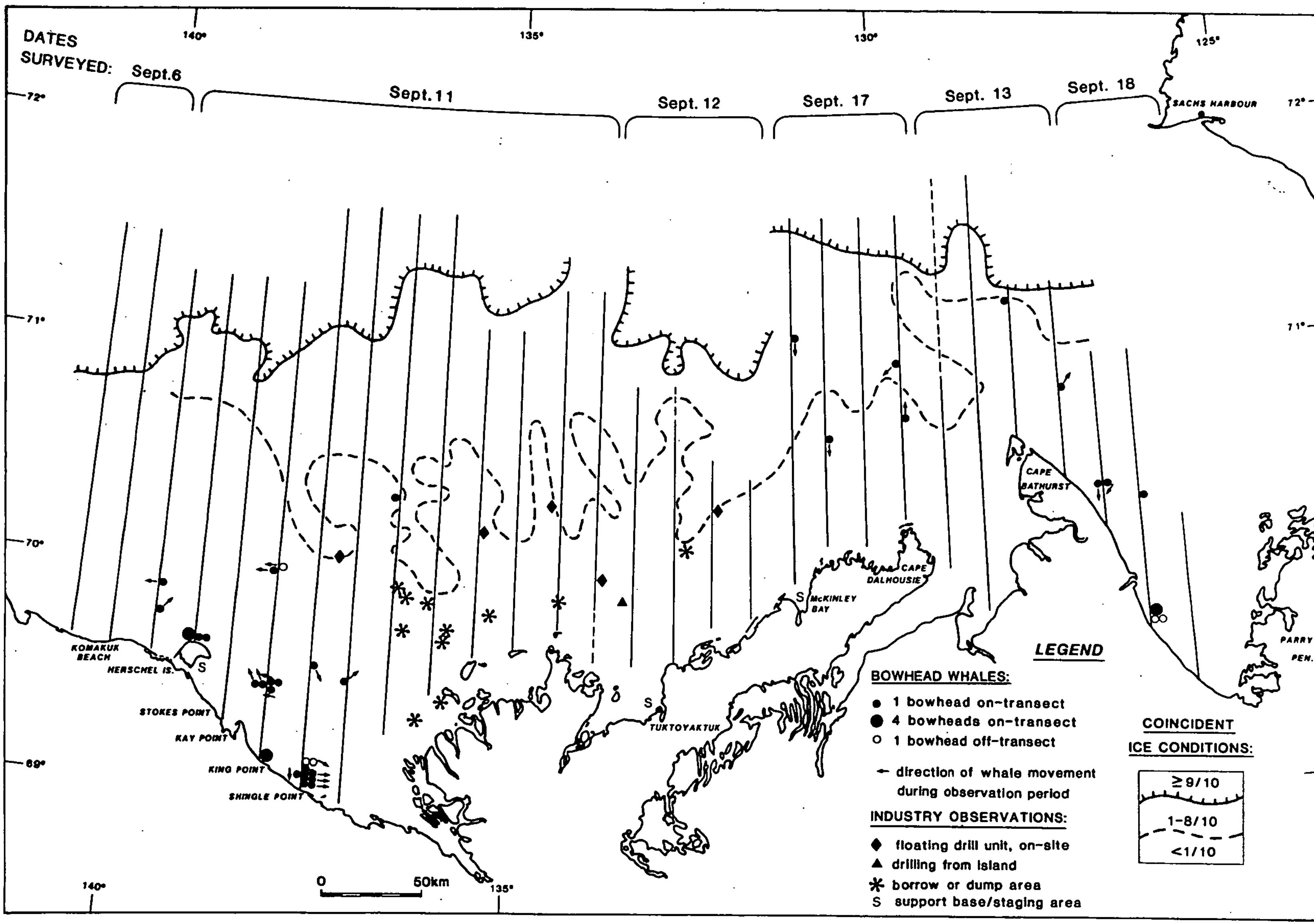


Figure 11. Bowhead whale sightings -- systematic surveys, 6-18 September 1984.

Sampling Intensity

To improve the accuracy of bowhead abundance estimates, sampling intensity was increased in three areas of the southeast Beaufort Sea where bowheads were concentrated in late August 1984. This approach provided the opportunity to compare uncorrected bowhead abundance estimates derived on the basis of 10 per cent coverage, with those derived using 30 or 50 per cent coverage in a concentration area and 10 per cent coverage of remaining areas in the zone. The results of these comparisons are given in Table 1.

Subdividing the Yukon Zone and increasing coverage to 50 per cent in the vicinity of Herschel Island resulted in an estimate of abundance (estimate: 30 whales) equal to that derived with 10 per cent coverage of the entire zone. However, in the West Amundsen Zone, estimated bowhead abundance was lower (61 whales) when the zone was subdivided and sampling intensity increased in two bowhead concentration areas (80 whales estimated for entire zone when coverage was 10 per cent). After applying the correction factors for submerged and undetected surfaced whales (see next section), the difference translates into a discrepancy of about 100-200 bowheads. Because the present study was designed to identify broad trends in relative abundance and distribution of bowheads, a discrepancy of this magnitude probably would not influence results to the extent that overall trends would be misrepresented.

ESTIMATES OF ABUNDANCE

This investigation was not designed or intended to provide estimates of the actual number of bowheads in the southeast Beaufort Sea. However, an approximate estimate of the number of bowhead whales present in the study area during each survey is useful for broad comparisons with past years, and has been attempted. Zonal densities and uncorrected estimates of abundance are shown in Table 2, densities are shown on Figure 12, and corrected estimates of abundance are provided in Table 3.

It was beyond the scope of the present program to derive the correction factors which were necessary to account for:

- surfaced animals undetected by observers
- animals that were submerged during the passage of the survey aircraft.

TABLE 1

Comparison of bowhead densities and abundance using sampling intensities of 10, 30, and 50 per cent

Zone	Approximate coverage per cent	No./1000 km^2	Estimated no. present (uncorrected)	
Example 1 27 August 1984				
Yukon Zone (entire)	~10	1.0	30	
Yukon Zone (minus Herschel Zone)	~10	0.7	20	30
Herschel Zone	~50	5.8	10	
Example 2 23 August 1984				
West Amundsen Zone (entire)	~10	5.6	80	
West Amundsen Zone (minus Baillie and Franklin zones)	~10	1.7	21	
Baillie Zone	~30	12.4	14	61
Franklin Zone	~50	35.1	26	

TABLE 2

Densities and Estimated Number of Bowheads in the southeast Beaufort Sea
July-September 1984
No./1000 km^2 (estimated number present)[a]

Survey period	Zone			
	Yukon	Delta	Tuk. Pen.	West Amundsen
5-9 July	0 (0)	0 (0)	1.2 (12)	NS
13-18 July	2.4 (56)	0 (0)	0 (0)	NS
21-23 July	7.3 (146)	3.1 (79)	1.0 (19)	NS
28 July-2 Aug.	3.0 (115)	2.7 (28)	3.9 (85)	NS
18-27 Aug.	YZ 0.7 (20) and HZ 5.8 (10)	1.1 (36)	1.9 (71)	WA 1.7 (21) and BZ 12.4 (14) and FZ 35.1 (26)
6-18 Sept.	8.8 (260)	0.6 (18)	1.5 (39)	8.7 (84)

a Not corrected for submerged or undetected surfaced bowheads.

NS = Not surveyed
HZ = Herschel Zone
BZ = Baillie Zone
FZ = Franklin Zone
YZ = Yukon Zone except area encompassed by HZ.
WA = West Amundsen Zone except area encompassed by BZ and FZ.

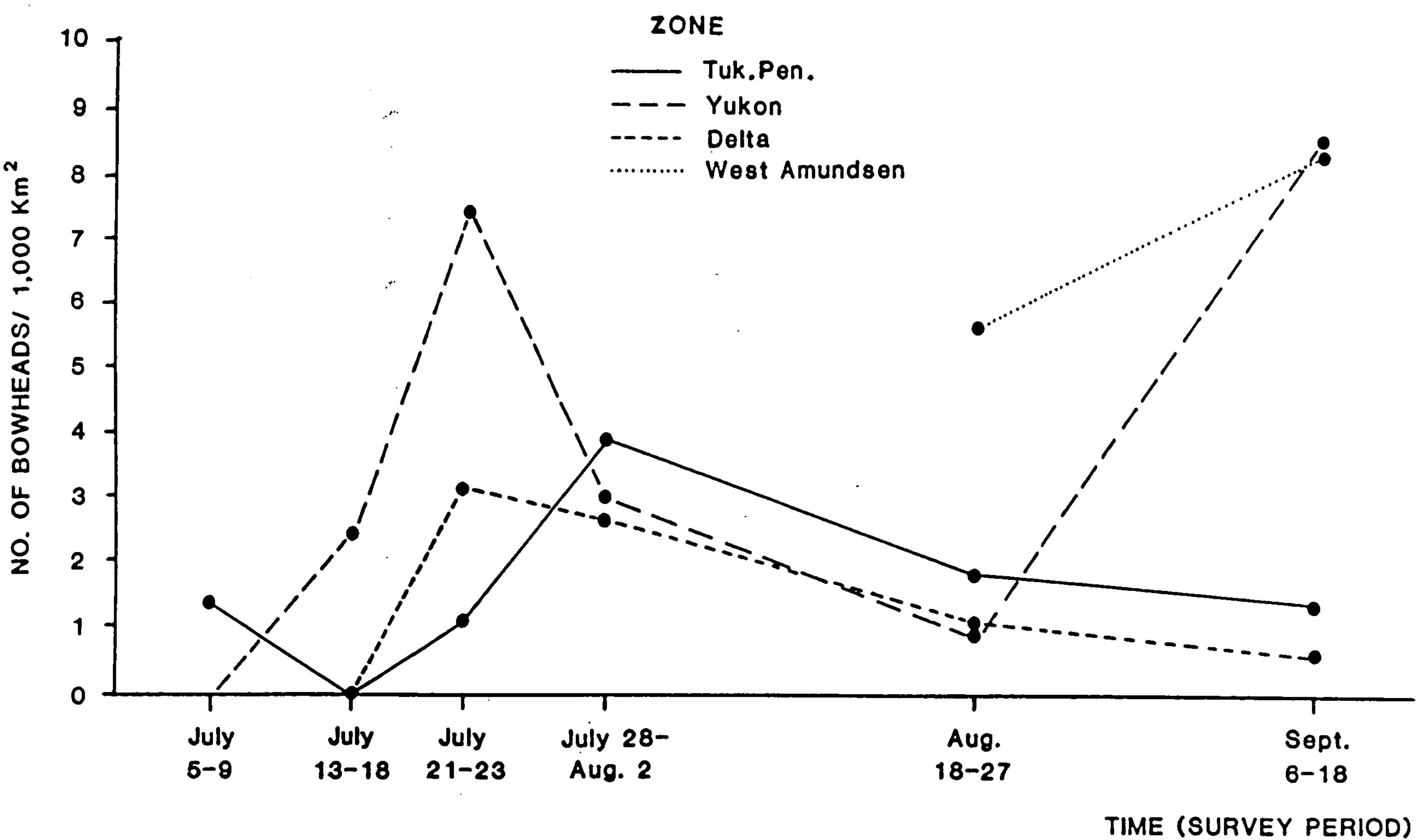


Figure 12. Observed bowhead densities in the southeast Beaufort Sea, July-September 1984.

TABLE 3

Corrected estimates of bowhead abundance[a] in the southeast Beaufort Sea, July-September 1984

Survey period	Zone: Yukon	Delta	Tuk. Pen.	West Amundsen	Total (Per cent of population)[b]
5-9 July	-	-	0-100	NS	100 (3)
13-18 July	200-300	-	-	NS	200-300 (5-8)
21-23 July	500-900	300-500	100	NS	900-1500 (23-39)
28 July-2 Aug.	400-800	100-200	300-500	NS	800-1500 (21-39)
18-27 Aug.	YZ 100 + HZ 0-100	100-200	300-400	WA 100 + BZ 100 + FZ 100-200	800-1200 (21-31)
6-18 Sept.	1000-1600	100	100-200	300-500	1500-2400 (39-62)

a Estimates rounded to nearest 100 (range reflects range of correction factors used).

b Based on a population size of 3871 bowheads (IWC 1984).

NS = Not surveyed
HZ = Herschel Zone
BZ = Baillie Zone
FZ = Franklin Zone
YZ = Yukon Zone, except area encompassed by HZ.
WA = West Amundsen Zone, except area encompassed by BZ and FZ.

Both are specific to a given study, and the latter is a function of whale surfacing behaviour (Leatherwood et al. 1982; Wursig et al. 1984a). Estimates in Table 3 were calculated using modified correction factors derived by Davis et al. (1982) and results reported by Wursig et al. (1984a). The accuracy of the factors used in relation to whale surfacing behaviour, to observers, and to observation conditions in 1984 is not known, but is expected to be reasonable, given the broad ranges used for the corrections.

CALF SIGHTINGS

No calves were observed during July through early August surveys, but three were observed during ferrying and reconnaissance flights in late August and September (see Figure 10). A fourth bowhead was tentatively identified as a calf in late August (see Figure 9). This unconfirmed sighting was the only one made on-transect during the 1984 systematic surveys.

If the aforementioned on-transect individual was in fact a calf, then this single sighting represented 1.3 per cent of all on-transect bowheads observed during the surveys in late August and September. This figure is believed to be an underestimate of the proportion of calves in the sample because calves probably have a lower detectability at each surfacing (smaller size, often inconspicuous blows). Furthermore, the detectability of calves may be lower than noncalves because they may spend proportionately less time at the surface, (Wursig et al. 1984b).

BOWHEADS SIGHTED BY INDUSTRY AND SUPPORT PERSONNEL

A total of 121 bowhead whales (57 sightings) was observed by industry and support personnel in the Canadian Beaufort Sea from July to October 1984. This total only includes those that were reported, and those reports where the species was identified. (An additional 26 whales were not identified to species.) Three bowheads were also recorded during systematic aerial surveys for seals in the southeast Beaufort Sea and in the north Amundsen Gulf in late June 1984[1].

---

1 M. Kingsley, unpublished data.

When provided by industry and support personnel, the locations of bowhead sightings are indicated on Figures 13, 14, and 15. The majority of sightings by industry and support personnel were recorded in the Delta Zone (62 per cent) and during the month of August (57 per cent). These figures reflect the timing and location of most industrial activity in the region.

DISTRIBUTION IN RELATION TO INDUSTRIAL ACTIVITY

One of the main objectives of this study was to examine bowhead distribution in relation to the location of industrial activity in the southeast Beaufort Sea. Sites of stationary industrial activity during 1984 are indicated on the bowhead distribution maps and on Figure 10, where they are named. Five drillships (Explorer I-IV and Kulluk), ten dredging operations (dump or borrow sites), and three staging and support areas (Tuktoyaktuk, McKinley Bay, and Pauline Cove) were active in the 1984 drilling season. Most of these activities were located within the Delta Zone, although a single drilling site, borrow site, and staging area were located in the Tuk. Pen. Zone, and one staging area and drilling site were located in the Yukon Zone. Bowheads were recorded occasionally in the vicinity (i.e., within 20-30 km) of mobile and stationary industrial activity within the Delta, Tuk. Pen., and Yukon zones by the authors, by Davis et al. (in prep.), by Richardson et al. (MS), and by industry personnel (see Figures 13-15).

These data indicate that a total exclusion of bowheads from the industry zone did not occur in 1984. Nevertheless, the number of bowheads observed in the industry zone was lower than the number observed in some areas outside of the industry zone. Consequently, the possibility that a proportion of the population was excluded cannot be discounted on the basis of the 1984 data discussed to the point. To evaluate this further, an understanding of the natural factors influencing bowhead distribution throughout the region must be gained. For this reason, several of the natural factors that may influence bowhead distribution were examined as part of this study.

ENVIRONMENTAL CONDITIONS IN THE SOUTHEAST BEAUFORT -- SUMMER 1984

Because the oceanographic portion of this study did not involve the collection of field data, and only a few in situ results from other studies and monitoring were available, almost all of what follows is derived from a qualitative analysis of patterns of water temperature and turbidity observed in the available satellite imagery and their changes

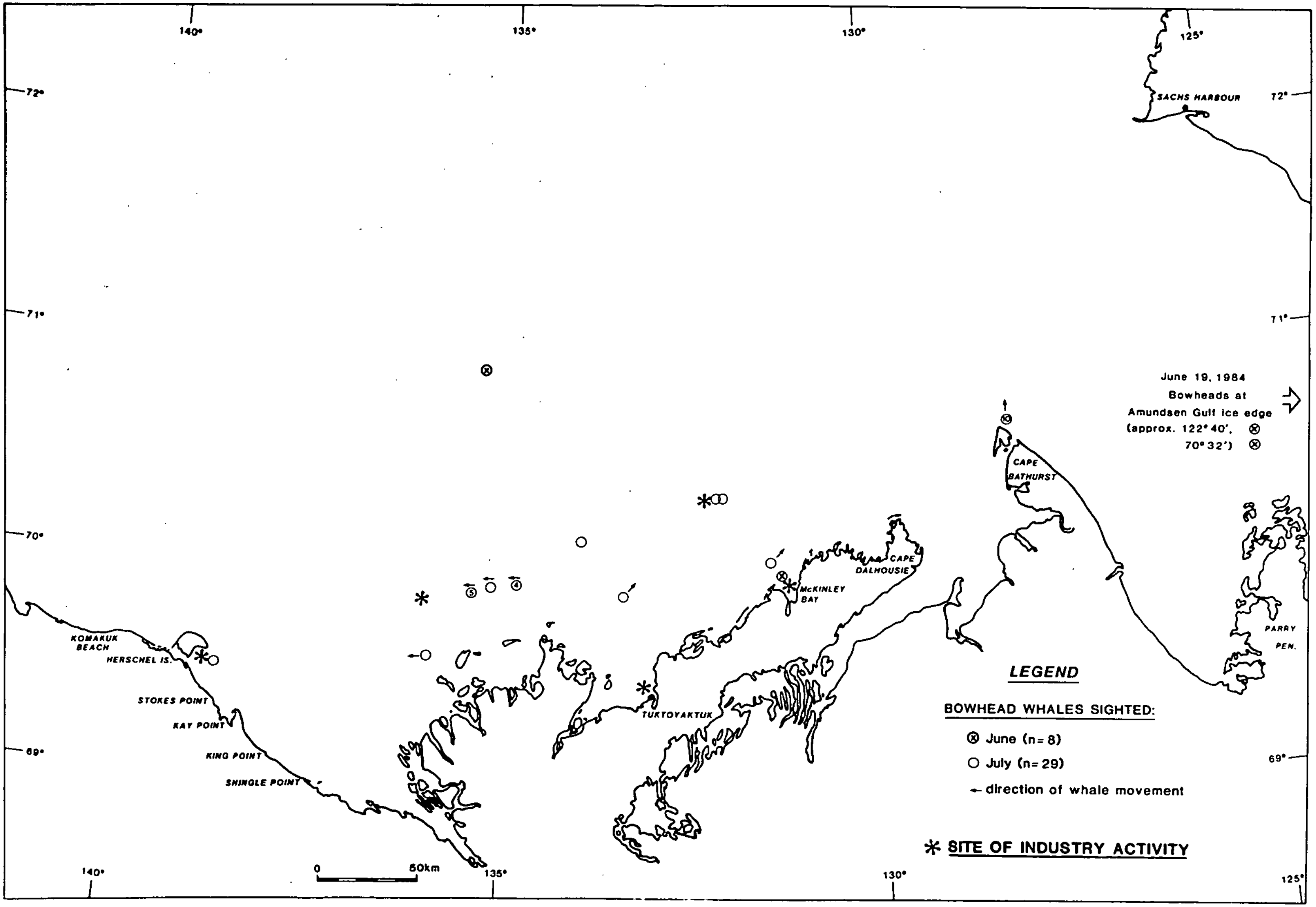


Figure 13. Location of bowhead whales sighted by industry and support personnel in the southeast Beaufort Sea, June-July 1984, and during systematic surveys for seals, June 1984.

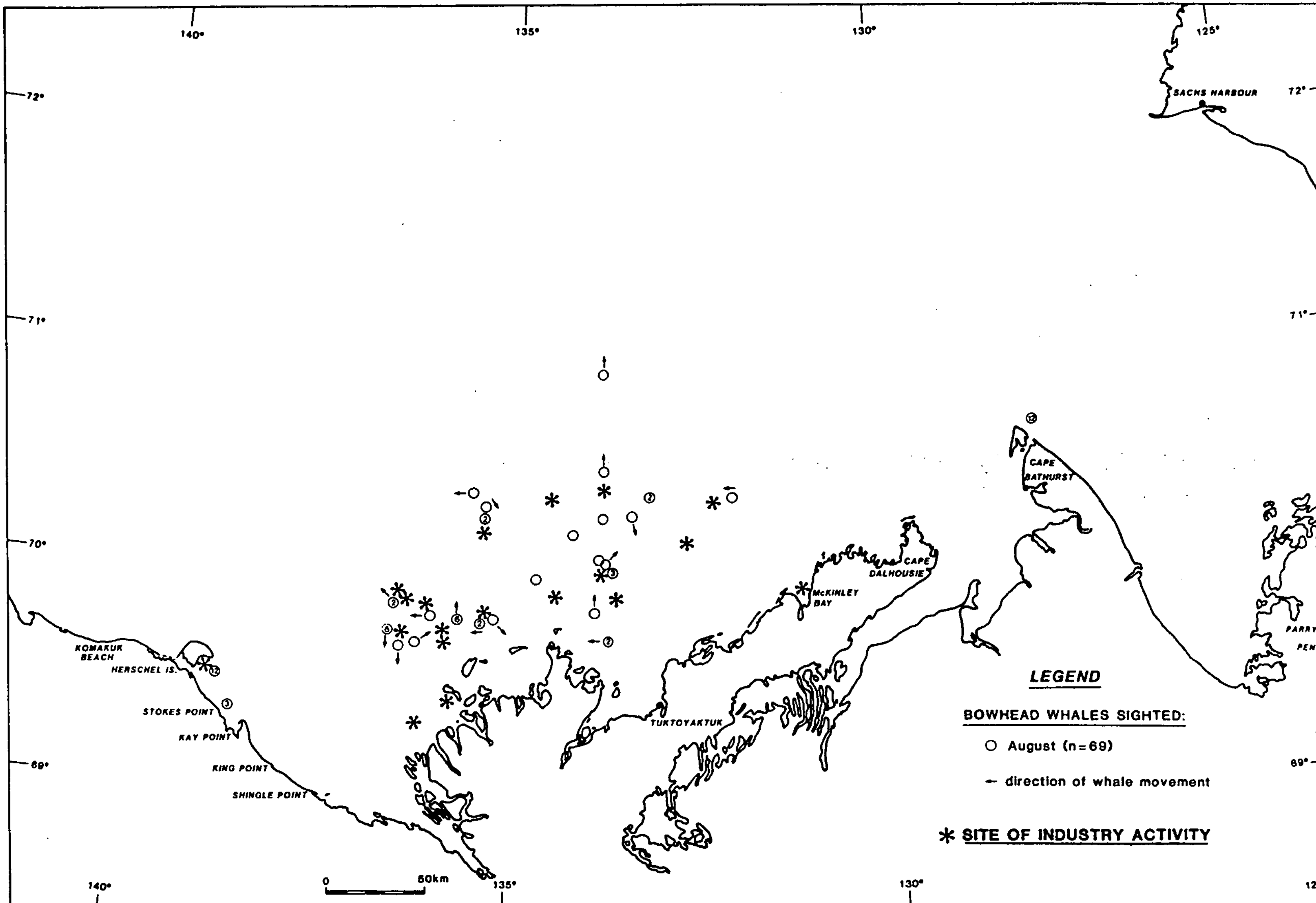


Figure 14. Location of bowhead whales sighted by industry and support personnel in the southeast Beaufort Sea, August 1984.

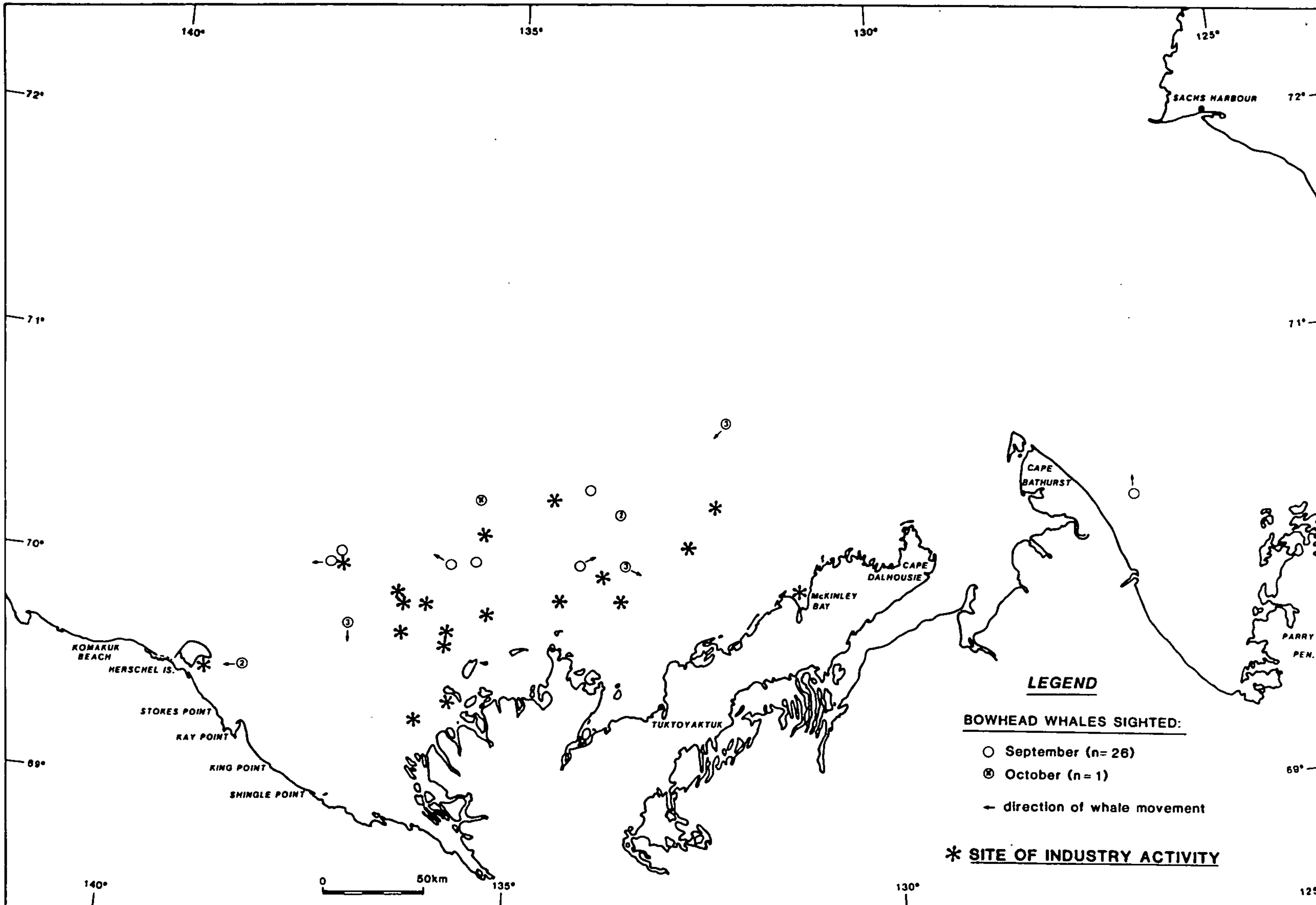


Figure 15. Location of bowhead whales sighted by industry and support personnel in the southeast Beaufort Sea, September-October 1984.

with time. Weather and ice information are largely from AES briefings and ice condition reports, supplemented with observations by the survey team.

June. Near-normal air temperatures occurred along the southeast Beaufort Sea coast during winter 1983-1984, whereas slightly warmer than normal air temperatures were recorded in spring 1984. In June and early July, mean daily temperatures averaged several degrees above normal. As a result, a large lead of open water and broken ice (1/10 to 6/10 concentration) developed in early June along the fast ice edge within Amundsen Gulf and offshore of the Tuktoyaktuk Peninsula. The fast ice west of a Cape Parry-Nelson Head arc fractured in early June, and vast (2 to 10 km across) and giant (over 10 km across) floes of ice moved into waters southwest of Banks Island. By June 28, the fast ice along the Tuktoyaktuk Peninsula had completely fractured, and <1-3/10 concentrations (55 to 110 km in width) occurred along the coast from west of the Amundsen Gulf fast-ice edge to midway between Komakuk Beach and Barter Island. Several vast and giant floes (that had broken away from the fast-ice) were also moving within this area of open water and broken ice. In late June, the fast ice across Amundsen Gulf was still intact, although large cracks had appeared.

July. An earlier than normal break-up pattern was experienced in all areas of the southeast Beaufort Sea during early July. In part because of generally offshore (easterly) winds during the first three weeks of July, this was a period of expansion in the area of open water and retreat of the ice edge. By mid-July, the main pack-ice edge was located just north of the drilling sites, about 80 km offshore. Giant ice floes (over 10 km across) were drifting westward out of Amundsen Gulf. Frequent periods of westerly, onshore winds throughout the last part of June and the first two weeks of July reversed this trend. During the general contraction of the open water area that followed, almost all thermal structure outside of the turbidity plume was erased, and the plume itself was pushed toward the coast, roughly lying along the 10-m isobath.

August. During August, there were frequent periods of westerly winds, particularly during the latter half of the month. Average air temperatures were below normal. As a result of this wind regime, there was a general onshore drift at the sea surface, and the width of the open water area along the Tuktoyaktuk Peninsula was reduced to 30-70 km. Open (4/10 to 6/10 concentration) areas of first-year and multi-year ice drifted throughout the hydrocarbon exploration zone.

Only one cloud-free satellite image (22 August) was available for the period of the late August survey. Plates 1 and 2 show turbidity and sea surface temperature patterns, respectively, on that date. In these and Plates 3 and 4 sea surface temperature and turbidity are depicted as increasing from blue (coldest, clearest) through green,

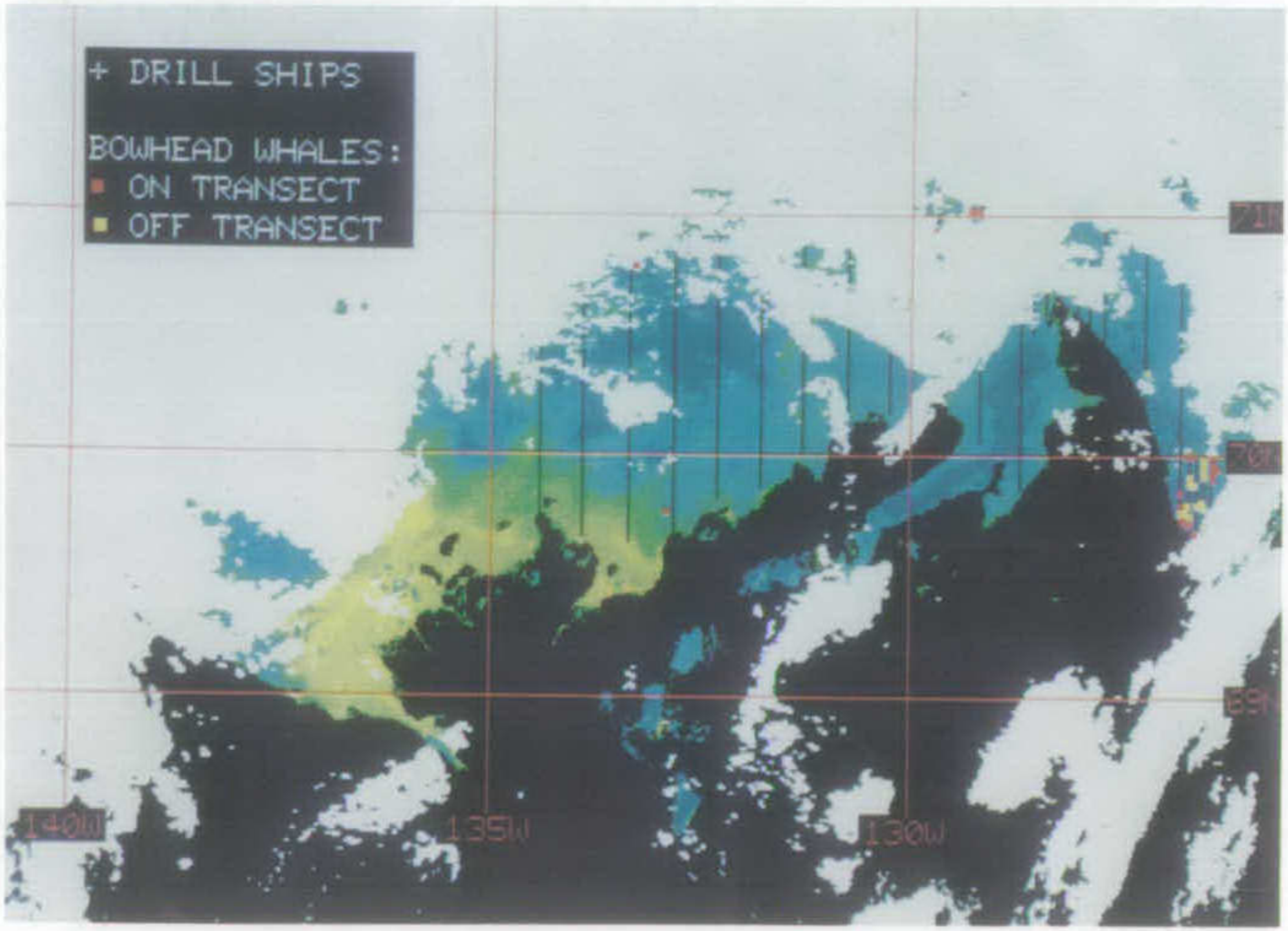


Plate 1. Surface turbidity patterns in the southeast Beaufort Sea, 22 August 1984.

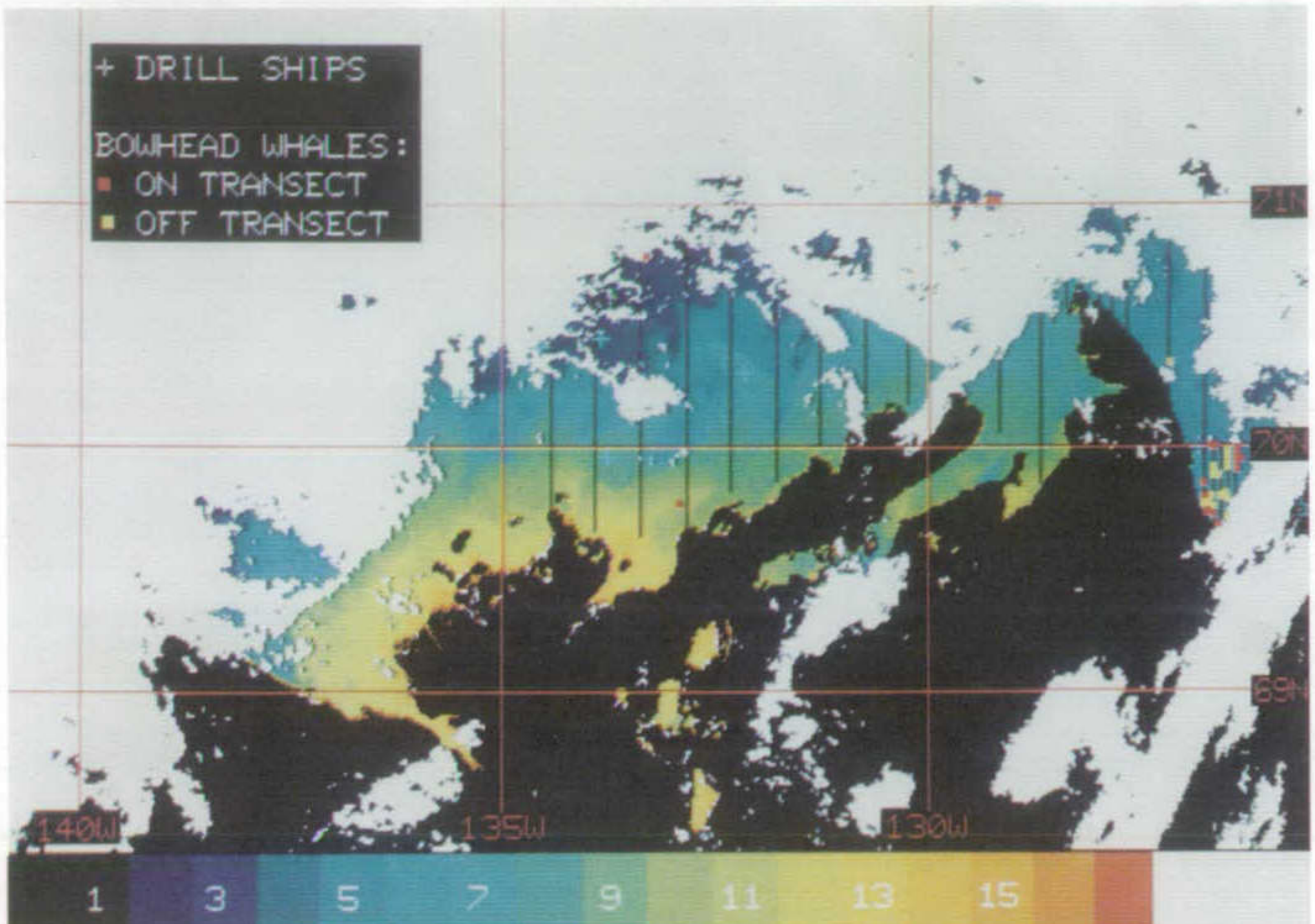


Plate 2. Sea surface temperature patterns in the southeast Beaufort Sea, 22 August 1984.

yellow to red (warmest, most turbid). The drillships are indicated by crosses; flight lines for the day of the image and one day following are shown as vertical lines. The locations of bowheads sighted are depicted as squares, the colour of which indicates the type of sighting, the size of which indicates the number of whales seen in that area.

The distribution of temperature and turbidity patterns on 22 August suggests a transition from an eastward surface flow to a westward flow, consistent with changes in the wind regime on the four days before this image. However, in situ data (CTD[1] data, current meter records) would be required to confirm this interpretation. A large body of very bright (turbid) water can be seen around Richards Island, but relatively little is evident offshore of the Tuktoyaktuk Peninsula.

To map the location and magnitude of thermal fronts and gradients in the study area, an approximate first derivative of the 22 August and 11 September thermal images was calculated. This was done by using a mathematical operator, which for every pixel in the image, set the value of pixel (x,y) to the maximum difference between that pixel and the eight pixels surrounding it. The resulting images (Figures 16 and 17) therefore represent the maximum temperature change over a 1-1.5-km distance in a 3-km x 3-km square for every point in the image. On the outer shelf, a series of sharp thermal fronts (many greater than 1°C/km) separated the warmer water close to the coast from colder water in the vicinity of the ice pack (see Figure 16). Thermal and turbidity contrast in the area surrounding Cape Bathurst was much less, because of the distance from the source of warm, turbid water (the Mackenzie River) and the proximity of the ice pack. In spite of this, there are indications of vigorous surface water movements that appear to be associated with an easterly flow past the Baillie Islands and into the Amundsen Gulf. Strings or streamers of brash ice, which are created when surface currents sweep bits of ice out of loose pack ice, neatly outline several eddies and curls that have been interpreted as the result of a flow into an area with no free exit.

<u>September</u>. During the first two weeks of September, the wind regime was generally easterly. Average air temperatures over the southeast Beaufort Sea were near normal for the first half of the month, but several degrees above normal during the second half. These temperatures, in conjunction with the mean offshore drift at the sea surface, resulted in mainly open water conditions in the drilling site area throughout September. The leading pack-ice edge off Kugmallit Bay receded north of latitude 70°30'N (about 150 km offshore) by the end of the month. Variable amounts of very open (1/10 to 3/10 concentration) to open (4/10 to 6/10) pack ice occurred south of that latitude, near the Alaskan coast and near Cape Bathurst.

Satellite imagery from which to infer oceanographic conditions was available for 8, 11, 12, 14, and 17 September. Although the 11 September images (Plates 3 and 4) do not delineate the northern edge of

---

1 CTD - Conductivity, temperature, density

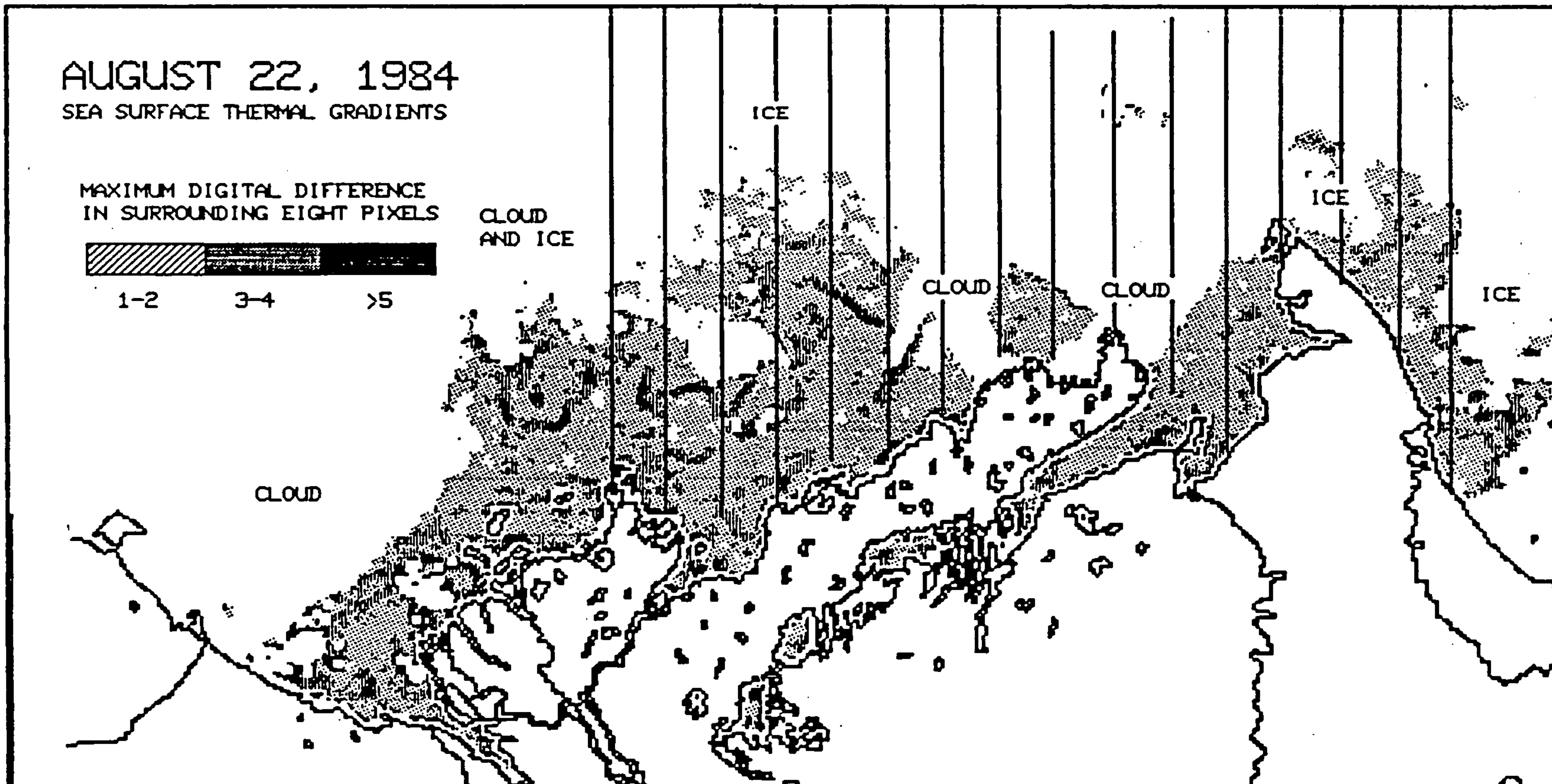


Figure 16. Sea surface thermal gradients in the south Beaufort Sea, 22 August 1984.

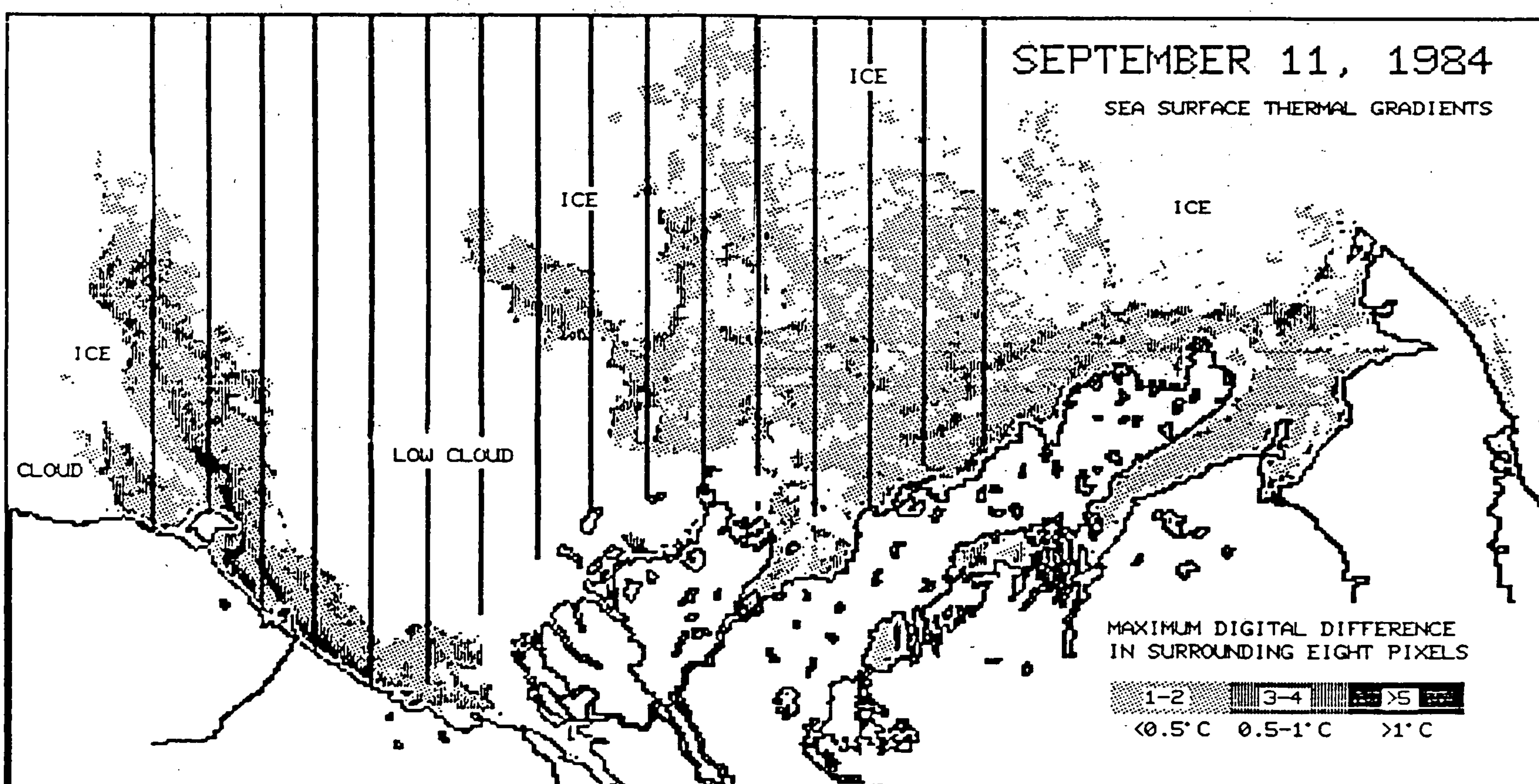


Figure 17. Sea surface thermal gradients in the south Beaufort Sea, 11 September 1984.

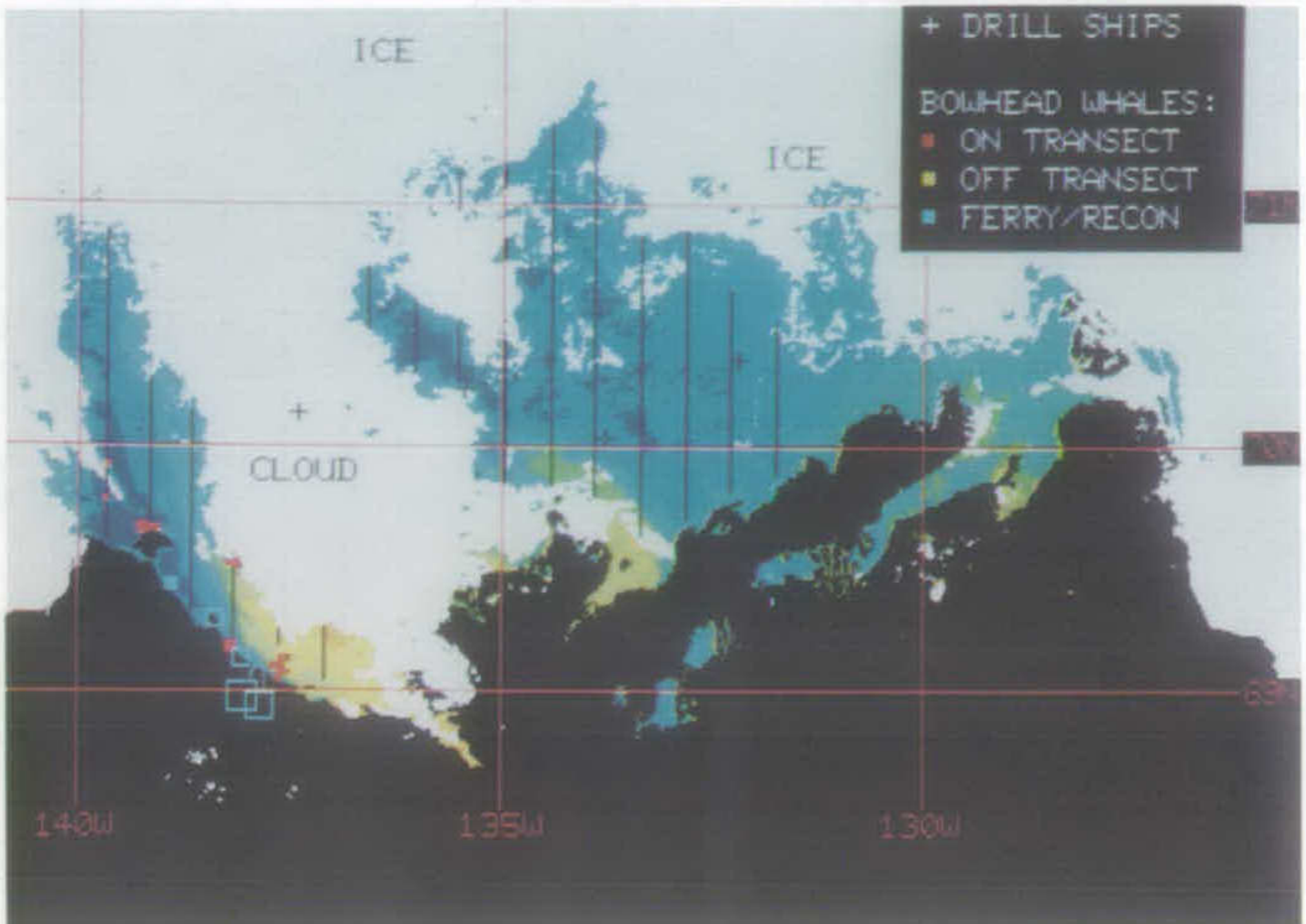


Plate 3. Surface turbidity patterns in the southern Beaufort Sea, 11 September 1984.

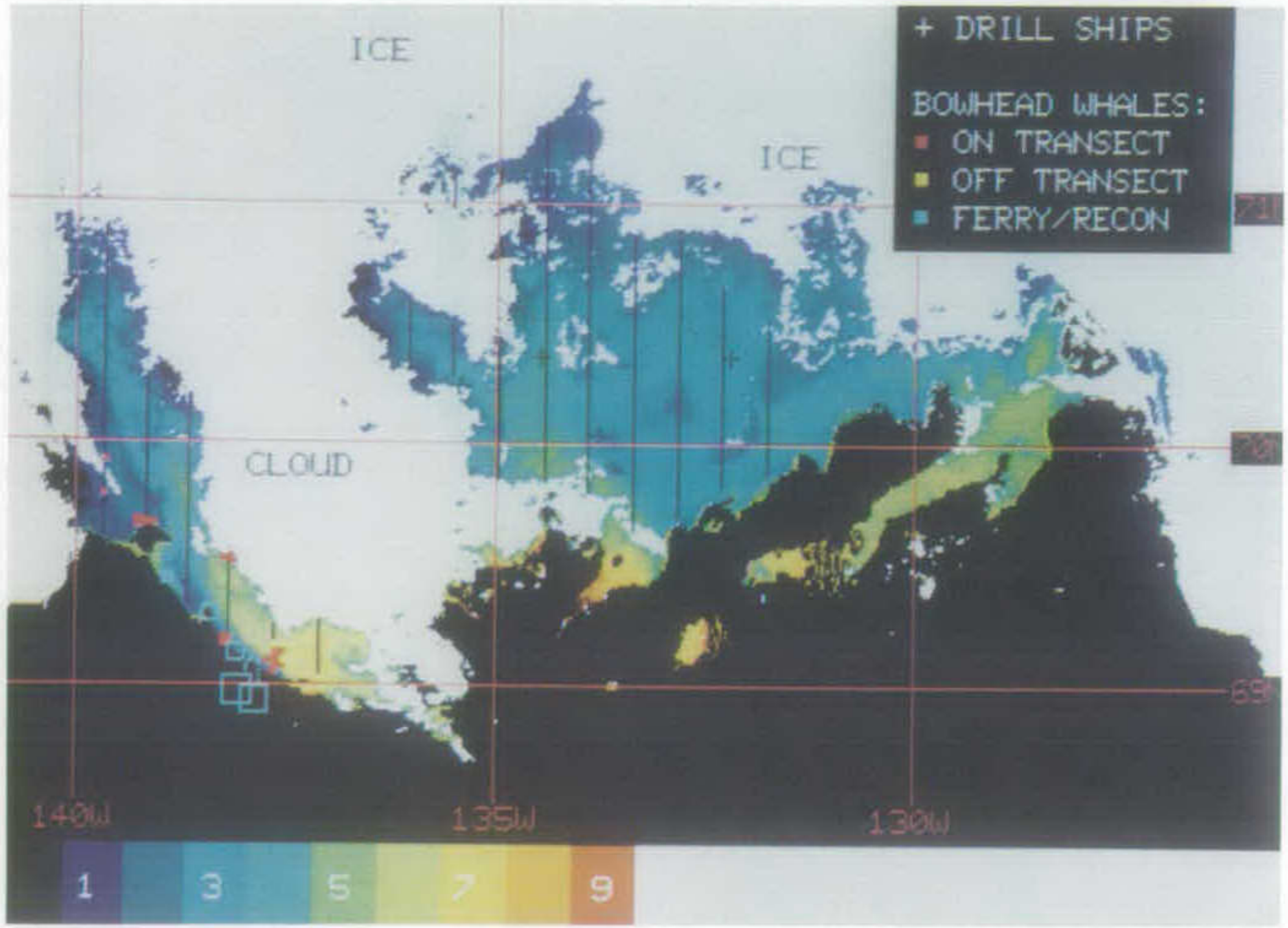


Plate 4. Sea surface temperature patterns in the southeast Beaufort Sea, 11 September 1984.

the river plume in Mackenzie Bay, its position was located with the use of visual observations and imagery for subsequent days (Figure 18). A combination of all available data shows the rapid northwestward extension (between 22 and 27 August) of a large tongue of warm, turbid water at an average rate of 10 to 12 cm/s, and the development of a clock-wise anti-cyclonic eddy on the Tuktoyaktuk Shelf. This movement coincided with a period of 15 to 40 knots northerly (onshore) winds that began 25 August and is the expected result of a northerly or easterly wind regime (Herlinveaux and de Lange Boom 1975; MacNeill and Garett 1975). Between Herschel Island and Shingle Point, the river plume was separated from the coast by colder, clearer water and the sharpest gradients seen anywhere in this image (2.5°C/km, see Figure 17). The location, temperature, and turbidity patterns suggest that this was a prograde, upwelling front in which the isopycnals (lines of equal density) slope upwards towards the coast (Owen 1981; Herlinveaux and de Lange Boom 1975). This interpretation is consistent with the combination of a less-dense surface water mass flowing to the west along a coastline, and steep bottom slopes in this region.

Elsewhere in the study area, a small, warm, and turbid plume can be seen issuing from Kugmallit Bay, and bending towards the Northwest under the influence of the easterly wind. The eastern edge of this plume, which was under a light mist or fog, was probably a retrograde, estuarine front in which the isopycnals slope outwards from the coast (Owen 1981). The thermal gradient across this front was from 0.5 to 1°C/km.

There were few data with which to describe the eddy seen off the Tuktokyaktuk Shelf, but they are consistent with a net drift during early September of warm, fresh, less-dense surface waters towards the North under the influence of easterly winds. Flow against the pack-ice may have been responsible for the circular motion and the formation of an ice string visible along the eastern edge of the eddy. Cold water was also being pulled out into the open water region and a moderate thermal gradient of three to four units/km can be seen in this area (see Figure 17). Levels of surface suspended materials (turbidity) in the eddy and across the Tuktoyaktuk Shelf were below the detection limits of the sensor.

RELATIONSHIP BETWEEN OBSERVED BOWHEAD DISTRIBUTION AND ENVIRONMENTAL FEATURES

Water Depth, Bottom Topography, and Ice

The distribution of bowheads with respect to water depth has been reported routinely since the bowhead systematic surveys began in 1980. Although water depth per se has some physical significance with

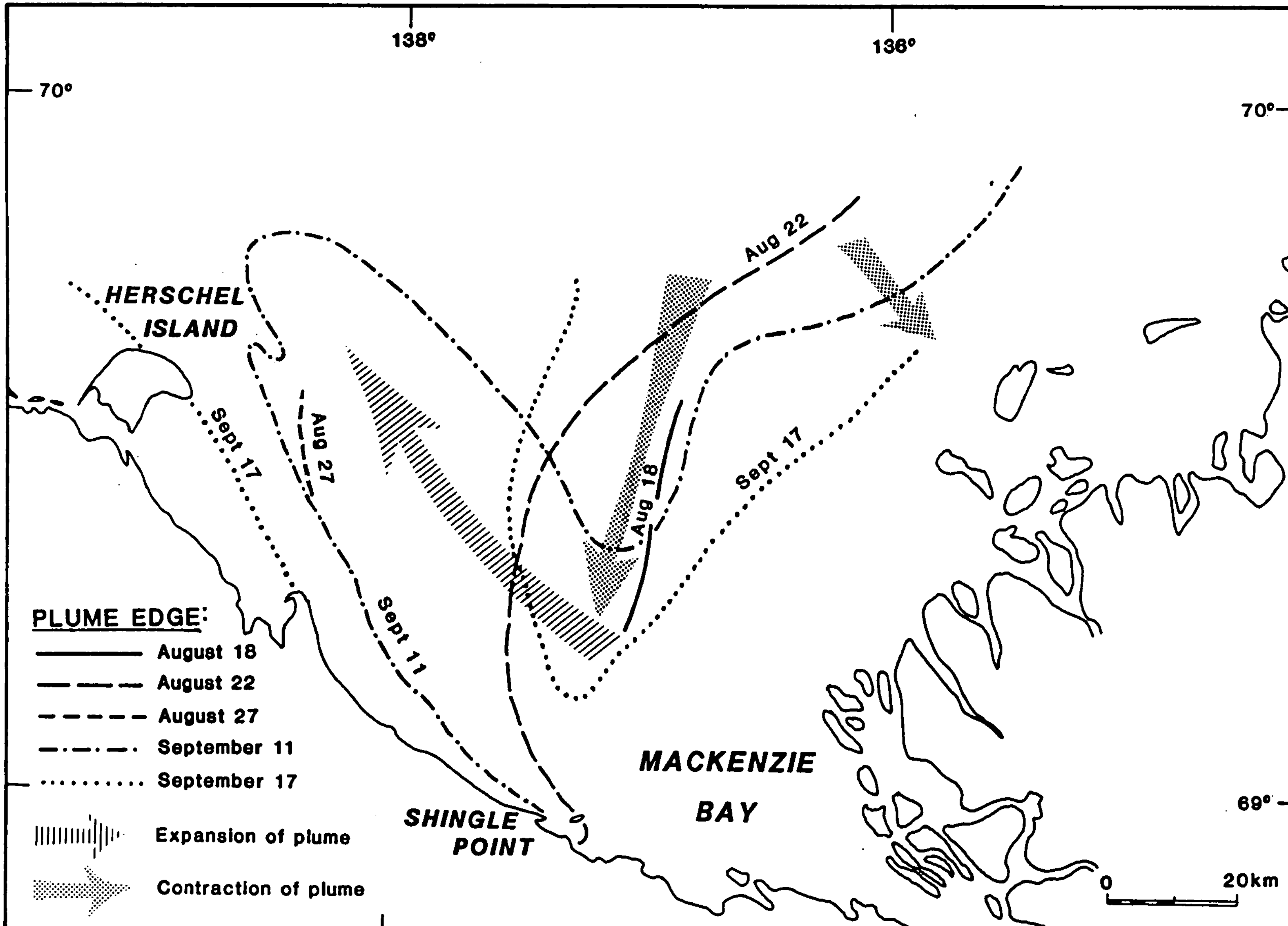


Figure 18. Evolution of the Mackenzie plume, 18 August-17 September 1984.

respect to plankton biology, the relationship between water depth and its influence on bowheads for food availability has many links. In this study, the distribution of bowheads was significantly non-uniform (within the categories of <50 m, 51-100 m, >100 m) only during the 21-23 July survey (chi-square = 12.57, df = 2, $p<0.005$). Eight of the 13 sightings were in the 51- to 100-m depth category marking the edge of the continental shelf.

The slope of the bottom, and particularly rapid changes in slope such as occur at the shelf break, may be more important than water depth. The physical mixing processes often change in the vicinity of the shelf break (Owen 1981; Denman and Powell 1984), and physical fronts and biological discontinuities can occur there. Bowheads have been observed in the vicinity of the shelf break in past studies (Harwood and Ford 1983; Cubbage et al. 1984), and in 1984 by the authors and others near and north of Cape Bathurst[1].

The physical presence of ice probably has a more direct effect on bowhead behaviour (and distribution) than water depth or some other oceanographic parameters. It can directly affect bowhead surfacing behaviour (Wursig et al. 1984b), and can affect bowhead distribution simply through physical obstruction. Furthermore, the distribution of the ice is itself dynamic, and is related to water depth, wind, and temperature.

The total area sampled over five ice concentration categories (ice-free, <1/10, 1-3/10, 4-6/10, 7-9/10) was calculated for each survey (Table 4). Overall, the results suggest that use of ice-covered waters by bowheads probably decreased throughout the open-water period, even given that each ice concentration category was sampled in each survey. Bowhead distribution was statistically non-uniform with respect to the ice categories in the 21-23 July survey (chi-square = 16.2, df = 4, $p<0.005$), and in the 6-18 September survey (chi-square = 20.17, df = 4, $p<0.001$). In the 18-28 August survey, the distribution among the ice categories was statistically uniform (chi-square = 4.13, df = 4; $p<0.5$). However, the sampled areas represented only 5 to 10 per cent of the area within the study boundaries, so it is not known if these trends and percentage of ice sampled in each category were representative of unsurveyed areas.

Water Temperature and Turbidity Patterns

July. With the exception of one bowhead observed near Herschel Island, all July sightings coincident with cloud-free images were located within open pack ice or in clear, cold, offshore waters, exhibiting little

---

1 M. Nerini, unpublished data.

TABLE 4

Per cent of area surveyed and per cent of on-transect bowhead sightings (in parentheses) by ice concentration category and survey dates, 1984

Survey Period	Ice concentration					
	Ice-Free	<1/10	1-3/10	4-6/10	7-9/10	Total km^2 surveyed (total bowhead sightings)
5-9 July	38 (100)	13 (0)	15 (0)	14 (0)	20 (0)	3,536 (1)
13-18 July	20 (0)	4 (0)	33 (100)	24 (0)	19 (0)	2,612 (1)
21-23 July	13 (0)	11 (46)	28 (15)	21 (15)	27 (23)	3,861 (13)
28 July-2 Aug.	35 (17)	32 (33)	11 (33)	7 (0)	14 (17)	2,736 (6)
18-27 Aug.[a]	20 (25)	24 (35)	22 (25)	11 (8)	23 (5)	10,791 (20)
6-18 Sept.	39 (79)	28 (14)	17 (7)	2 (0)	14 (0)	9,918 (29)

[a] Results from transects 1-28 only (~10 per cent coverage).

detectable thermal or turbidity variability. The group of animals observed north of Shingle Point (see Figure 6) was more than 10 km away from the plume edge.

August. Figure 19 and Table 5 summarize the distribution of bowheads compared to observation of water colour made by the observers during the survey in late August. There is agreement between the patterns of water colour recorded by the observers and that seen in imagery for the same day, but differences in spatial resolution are evident (20 km between flight lines versus 1 km in the imagery).

Only three bowheads were seen on 22 August, (see satellite images Plates 1 and 2) and only one of these was in an area where comparisons with temperature and turbidity patterns were possible. This sighting, another made in Mackenzie Bay on 18 August, and results of others (Davis et al. in prep.; Richardson et al. MS) indicate that bowheads were using the edge of the river plume in 1984. The single animal seen on the 22 August systematic survey was near the edge of a small thermal plume issuing from Kugmallit Bay (gradient of 0.5-1.5°C/km), whereas the animals seen on the 18 August survey were noted by observers immediately seaward of the very turbid river plume in Mackenzie Bay (no cloud-free image of this area).

Even though there were many thermal gradients (several greater than 1.5°C/km) in the northern portion of the open water area on the Tuktoyaktuk Shelf (see Figure 16), no bowheads were seen in this area on the August surveys. Suspended, particulate material was low and near the limits of resolution of the sensor. No turbidity contrast could be detected across this area.

The largest numbers of bowheads seen in late August were near Cape Bathurst and in west Franklin Bay. Because the survey of this area was one day after the image shown in Plates 1 and 2, and vigorous surface circulation is evident, it is unwise to attempt a very close comparison of whales and features. However, 12 of the bowheads sighted on this day were within 1 km either of ice strings or of fronts visible from the aircraft.

September. Figure 20 and Table 5 summarize the location of bowheads sighted and observations of water colour on the 6 September survey. It is notable that during this survey, more than 40 per cent of the bowhead sightings were in waters described by the aerial observers as visibly turbid, muddy-brown or brown-green (see Table 5). One of these sightings was near a visible front between green and green-brown water marking the northern edge of the plume issuing from Mackenzie Bay. Five animals were seen near the western edge of the plume and the others were all associated with its southern edge or were within a few hundred metres of the Yukon coast. Large numbers of bowheads were not observed in turbid waters during other systematic surveys in 1984, but others (e.g., Richardson et al. MS) noted them there in August.

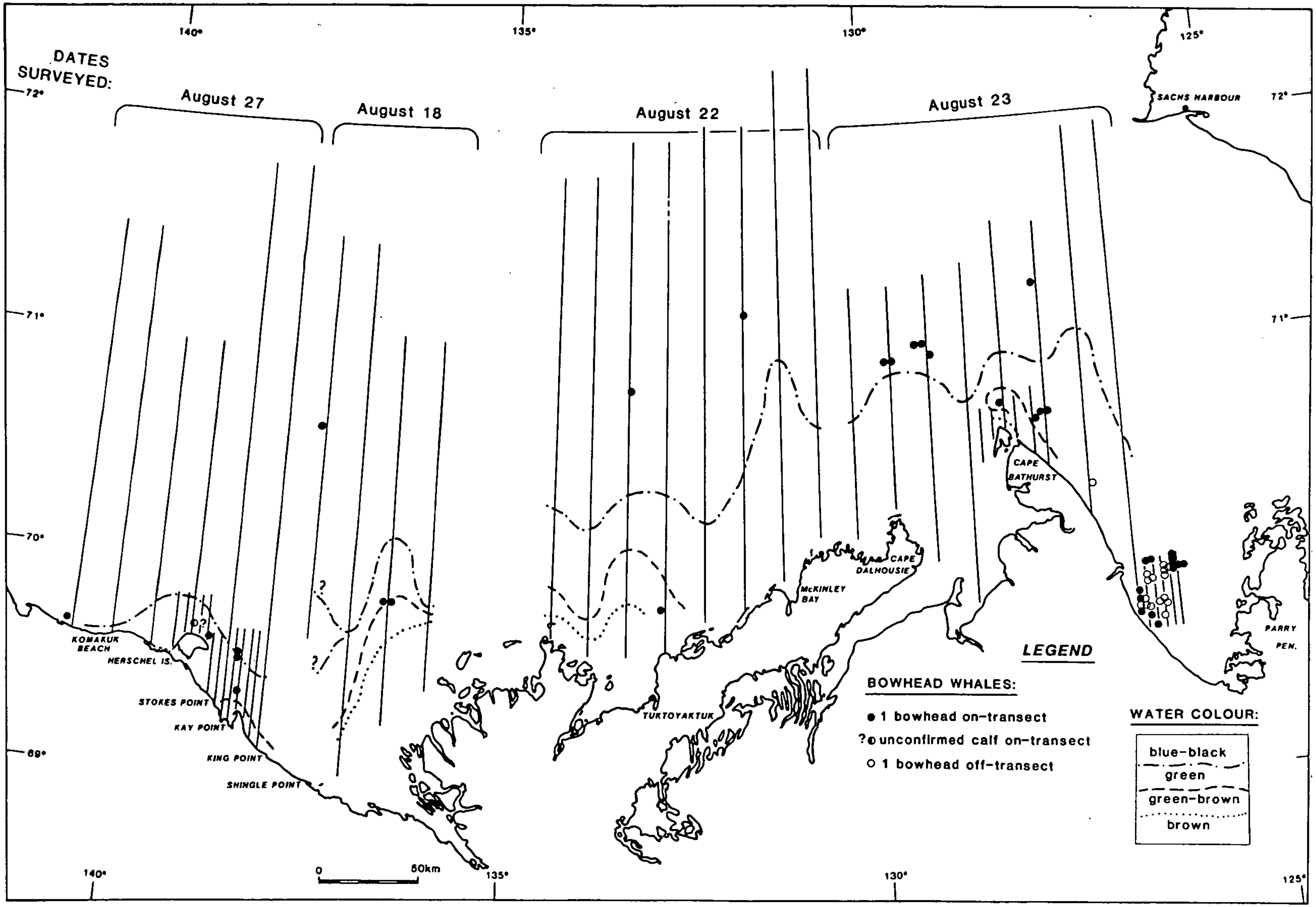


Figure 19. Bowhead whale sightings and observations of water colour during systematic surveys, 18-27 August 1984.

TABLE 5

Per cent of area surveyed and per cent of on-transect bowhead sightings (in parentheses) by water colour categories and survey dates, late August and September 1984

Survey	Water Colour					Total km^2 surveyed (total on-transect sightings)
	Muddy brown	Brown/ green	Green	Blue/ green	Blue/ black	
18-27 August[a]	2.6 (0)	4.0 (0)	7.6 (45)	14.9 (15)	70.8 (40)	10,791 (20)
6-18 September	3.8 (20.7)	9.0 (20.7)	8.7 (13.8)	20.5 (17.2)	60.0 (27.6)	9,918 (29)

[a] Results from transects 1-28 only (10 per cent coverage).

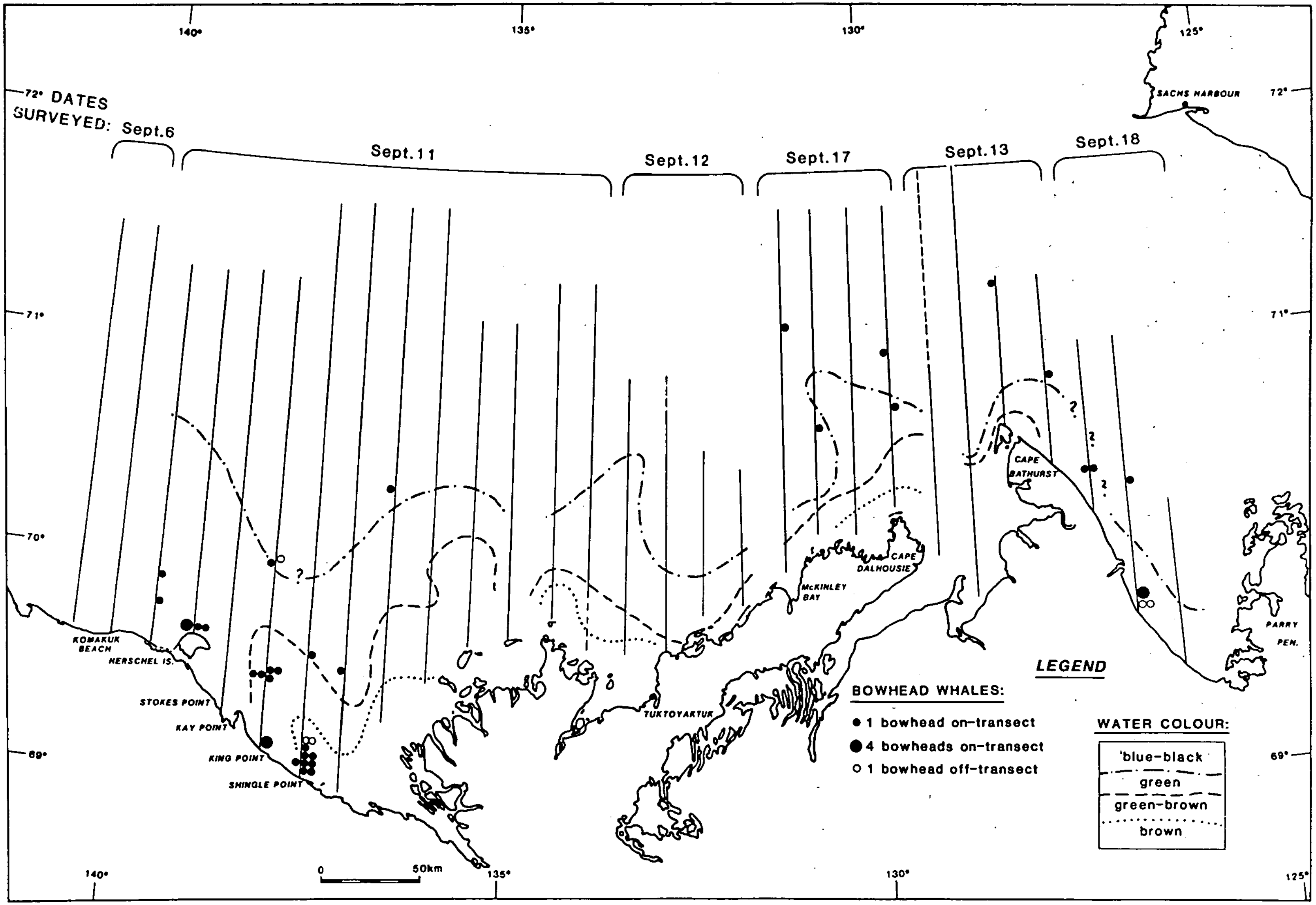


Figure 20. Bowhead whale sightings and observations of water colour during systematic surveys, 6-18 September 1984.

Because of the interest in the relationship between bowhead distribution and the location of oceanographic fronts and discontinuities, the relative thermal gradient at the location of each bowhead sighted has been extracted from the imagery. Table 6 and Figure 21 summarize the sea surface temperature gradients at the locations where the whales were sighted on 11 September. The analysis is restricted to the cloud-free area off the Yukon coast for this date, because this is the only area with coincident imagery and large numbers of whale observations.

Comparison of whale positions with satellite-derived turbidity patterns for 11 September (see Table 6) shows a slightly different relationship than that reported by observers. Of the bowheads seen in the cloud and ice-free areas on that day, the largest number of sightings (five of seven) and of individual animals (22 of 27) were found in cold, clear water around Herschel Island and near the Yukon coast (see Table 6). The airborne observers apparently did not detect the narrow tongue of cold, clear water between Kay Point and Shingle Point (compare Figure 20 and Plates 3 and 4), and the whales were noted as in turbid water. Because the satellite sensor averages the signal from 1-km squares, pixels within 1 km of the coast are excluded from the analysis and a very narrow band of coastal, turbid water reported by observers is ignored. Bowheads seen in this turbid water (as a result of turbulence near the shore rather than Mackenzie River water), will have been classified as being in clear water according to the authors' digital methods, but in turbid water by the observers.

On 11 September, along the Yukon coast, most (84 per cent) of the bowheads seen off- or on-transect were located near the steepest gradients and within 3 km of land, even though gradients of 1°C/km or greater constituted only 30 per cent of the line kilometres flown (see Figure 20). Mapping the thermal differences across the entire image shows that the greatest variability (steepest gradients) found in the southeast Beaufort on 11 September was along the Yukon coast (see Figure 17).

Another gradient at the mouth of Kugmallit Bay was not well delineated in the imagery because it was contaminated by a light mist, but was noted by airborne observers. No bowheads were seen at this front when it was crossed twice during systematic surveys on 12 September. Bowheads were also not observed during extensive systematic surveys of the deeper more uniform areas offshore, but a reconnaissance flight conducted later on this day, to examine the edges of the eddy visible in 11 September imagery, located two bowheads. A calf was observed near the string of brash ice marking the convergence at the eastern edge of the eddy, and another was found near the cold centre of the eddy as it was depicted in the 11 September imagery (see Figure 10, and Appendix 4). Both were at moderate thermal gradients (0.5-1.0°C/km).

TABLE 6

Satellite temperature and turbidity observations and number of bowhead sightings by temperature/turbidity categories -- comparison for the cloud-free area off the Yukon coast, 11 September 1984

Number of bowheads on-transect (per cent) versus digital value at the position of the bowhead sighting

Turbidity

Digital level in band 1	No. bowheads	No. groups	Line-km surveyed in each class
12 (clearest)	8 (30)	4 (57)	49 (26)
13	14 (52)	1 (14)	65 (34)
14	-	-	28 (15)
15	3 (11)	1 (14)	16 (8)
16	2 (7)	1 (14)	16 (8)
17 (most turbid)	-	-	16 (8)
	n = 27	n = 7	190 km

Temperature

Digital level	Approx. temp.	No. bowheads	No. groups	Line-km surveyed in each class
<115	>5.5	2 (7)	1 (11)	22 (12)
<120	>4.5	-	-	35 (18)
<125	>3.0	3 (11)	1 (11)	50 (26)
<130	>2.0	19 (70)	6 (67)	55 (29)
<135	>0.5	3 (11)	1 (11)	28 (15)
		n = 27	n = 9	189 km

TABLE 6 (Continued)

Number of bowheads on-transect (per cent) versus digital value at the position of the bowhead sighting

Temperature Gradient

Digital diff.	Thermal diff.	No. bowheads	No. groups	No. whales (ferry flights)	Line-km surveyed in each class
0	0	1 (4)	1 (7)	-	5
1	-	2 (8)	2 (13)	1	79
2	0.5	1 (4)	2 (13)	13	49
3	-	3 (12)	1 (7)	-	29
4	1.0	-	-	-	10
5	-	4 (16)	2 (13)	14	7
6	1.5	-	1 (7)	8	3
7	-	1 (4)	3 (20)	11	4
8	2.0	13 (52)	3 (20)	13	3
9	-	-	-	-	1
		n = 25	n = 15	n = 60	190 km

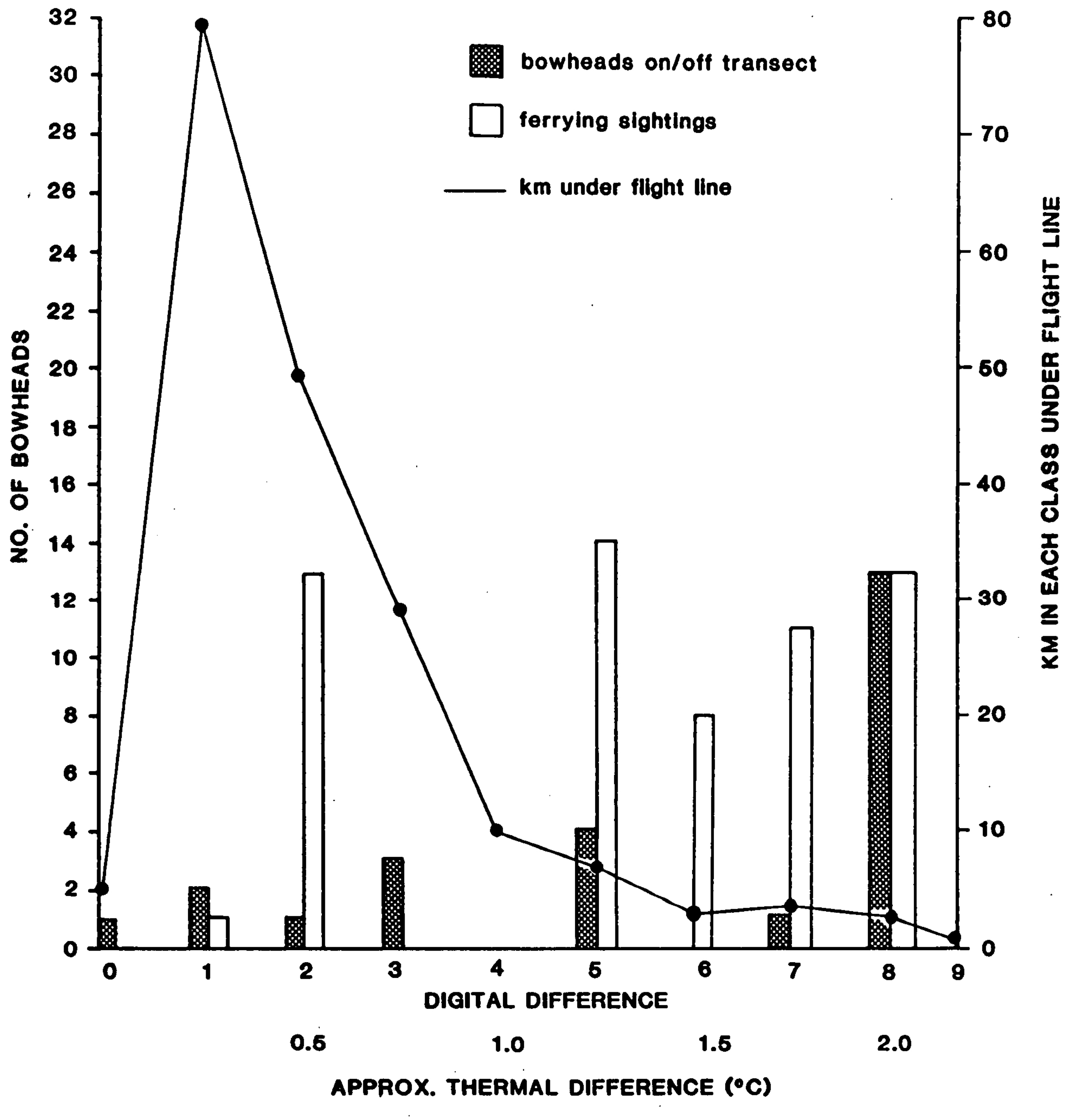


Figure 21. Bowheads sighted off the Yukon coast, 11 September 1984, vs. thermal gradients (maximum difference in surrounding eight pixels).

DISCUSSION

1984 SURVEY RESULTS

General Trends

Six systematic aerial surveys were completed in the southeast Beaufort Sea within the period from 5 July to 18 September 1984. Despite limitations associated with survey timing, progression, and methods, several broad trends in bowhead distribution, abundance, and behaviour were apparent.

Overall abundance of bowheads in the southeast Beaufort Sea increased from early July to September, although fluctuations were apparent within this period. The relative abundance of bowheads among zones and surveys provides some evidence regarding the timing and location of possible shifts in the distribution of the population. In general, however, the direction of whale movement noted at the time of the sighting is a less useful parameter for examination of population movements and shifts for two reasons. First, observers cannot distinguish between localized movements (e.g., responses to local prey abundance, wind direction, etc.,) and definite migratory movements; and secondly, the small sample size hampers identification of net directional movement.

Fewer than 300 bowheads were estimated to be present in the southeast Beaufort during the first half of July 1984. Between the 13-18 July and 21-23 July surveys, a large increase in bowhead numbers was noted. The estimated abundance increased from 200-300 to 900-1500, with densities of whales being higher in all of the zones surveyed. However, the data do not indicate clearly whether the whales arrived from Alaska, from Amundsen Gulf, from north of the study area, or from some combination of these regions.

The relative abundance of bowheads in the southeast Beaufort region remained relatively constant between the 21-23 July survey and the 28 July-2 August survey, when an estimated 900-1500 whales were present. However, the estimated number of bowheads in the southeast Beaufort Sea had apparently declined to 500-800 by the 18-27 August survey. An additional 300-500 bowheads were estimated to be present in the West Amundsen Zone. It is recognized that the apparent decrease in bowhead abundance noted during late August may have been as a result of the sampling (e.g., underestimation of the number of whales present owing to one or more reasons given under "Limitations of Survey Method"). However, movement of bowheads from the study area cannot be discounted as a possible explanation for the apparent decrease.

During the final survey in September, bowhead numbers apparently increased again. An estimated 1200-1900 bowheads were present in the southeast Beaufort Sea, whereas the estimated number of whales in the Cape Bathurst and Franklin Bay area was the same as in late August (300-500). Bowhead densities in the Delta and Tuk. Pen. zones were lower during the September survey than in late August. On the other hand, the estimated number of whales in the Yukon Zone increased from 100-200 in late August to 1000-1600 in September. These fluctuations may have been the result of sampling artifact or movement of bowheads into, and out of, the Yukon Zone. Movement of bowheads to and from the other zones could have also occurred, but was not apparent because numbers of whales in each of the other zones were similar from survey to survey.

A change in the general distribution of bowheads occurred along with the apparent fluctuations in bowhead abundance in the southeast Beaufort Sea. During the July surveys, most bowheads were observed more than 100 km offshore in association with pack ice (all concentrations). In contrast, bowheads observed in late August and September were most often in nearshore, ice-free waters and in relatively large groups. Ice concentrations $\geq$4/10 were extensively surveyed but used by few bowheads in late August and September, and overall, these areas were probably not as important for bowheads as other habitats. No detectable association of bowheads with the line of the shelf-break was noted during the 1984 surveys, except in the Cape Bathurst and Franklin Bay area.

Observed activities of bowheads also changed throughout the period of the 1984 surveys. Swimming at the surface, diving, and resting were the only activities noted in July, but behaviours indicative of feeding and socializing (as well as swimming at the surface, diving, and resting) were observed during surveys in late August and September. In addition, group sizes were generally larger in September than at other times.

Relation to Past Years

1984 was the fifth consecutive year of systematic aerial surveys for bowheads in the southeast Beaufort Sea during late August and early September. In 1980, systematic surveys were limited to the Tuk. Pen. Zone and to waters within the 50-m isobath. Surveys from 1981-83 were expanded to include the southeast Beaufort Sea between the Alaska-Yukon border west to Cape Bathurst. The seaward limit of the study areas varied from about latitude 72°N in 1981, to the 100-m isobath in 1982, and to 25 km seaward of the 100-m isobath in 1983. As in the present study, surveys in 1981 not only systematically covered the southeast Beaufort Sea in late July and early August, but also included more extensive coverage of Amundsen Gulf. However, 1984 was the first year in which surveys of the southeast Beaufort Sea were conducted during the first half of July.

Table 7 summarizes estimates of the number of bowheads present in the southeast Beaufort Sea during various survey periods from 1980 to 1984. Despite variable levels of survey effort, the results of the studies provide a broad indication of general trends in bowhead abundance and distribution in the southeast Beaufort Sea during these years.

The estimates provided in Table 7 have all been corrected to account for submerged whales and for surfaced whales undetected by observers. The authors did these corrections for 1981 and 1983 data (Davis et al. 1982; McLaren and Davis 1985), but corrections were not done for 1980 surveys (Renaud and Davis 1981) and were only partial for 1982 surveys (Harwood and Ford 1983). To compare the annual estimates, it was necessary to correct the 1980 and 1982 survey results. The factors used were based on results from other years or from other studies, so must be interpreted with caution. To correct both the 1980 and 1982 data for surfaced whales missed by observers, the extrapolated counts were multiplied by 1.43 and 1.54, respectively. These factors assume that 30-35 per cent of the surfaced bowheads are missed (see under "Aerial Surveys"). To correct the 1980 estimates for submerged whales, a factor of 2.6 has been applied which assumes that bowheads were visible at the surface 38 per cent of the time. This figure represents the mean time that bowheads were visible at the surface during 1980-1982 behavioural studies (Wursig et al. 1984b).

Systematic sampling was conducted during July in 1981 and 1984. Bowheads were apparently more abundant in the southeast Beaufort Sea during late July 1984 (estimated 900-1500 whales) than in late July 1981 (estimated 255 whales). There are many more years for comparisons of the late August and September survey periods. Table 7 illustrates the marked variability in estimates for the different zones in the years from 1980-1984. This variability may be the result of a sampling artifact, the application of inappropriate correction factors, a differential distribution among years, or a combination of these. Considering only major differences in estimates among zones, it appears that the Tuk. Pen. Zone was particularly important in late August 1980 and 1982, and in September 1983, and the Yukon Zone was important in 1982, late August 1983, and September 1984.

Table 7 indicates that the southeast Beaufort Sea has been used by substantial numbers of bowheads during late August, or September, or both, in all years in which surveys have been conducted. The total number of bowheads estimated to be present in southeast Beaufort region during late August and September 1981-1984 has been relatively constant (i.e., within the range of 1500 to 2000 in most years). The data suggest that the entire population has not been present in the areas surveyed in any year; and the authors believe that the other portion of the western Arctic bowhead population probably occurs in Amundsen Gulf (Davis et al. 1982; Hazard and Cubbage 1982) and the Alaskan Beaufort (Ljungblad et al. 1984) during August and September. It is also possible that the method used repeatedly underestimates the number of whales in the region.

TABLE 7

Estimated number of bowheads present in the southeast Beaufort Sea and Amundsen Gulf, 1980-1984[a]

Time of Survey	Southeast Beaufort Sea				Amundsen Gulf		
	Yukon	Delta	Tuk. Pen.	Total	West	East	Total
First half July 1984	-	-	0-100	0-100	NS	NS	NS
Second half July 1981	205	25	25	255	707	287	994
1984	500-900	300-500	100	900-1500	NS	NS	NS
First half August							
1980	NS	NS	100	100	-	-	-
1981	NS	2860	404	3264	228	0	228
Second half August							
1980	NS	NS	2800-3000	2800-3000	NS	NS	NS
1981	96	487	1496	2079	839	NS	839
1982	1700-1900	400	700	2800-3000	NS	NS	NS
1983	710-1103	117	660	1487-1880	NS	NS	NS
1984	100-200	100-200	300-400	500-800	300-500	NS	300-500
First half September							
1980	NS	NS	800-900	800-900	NS	NS	NS
1981	367	417	1050	1888	704	NS	704
1982	1600-1700	200-300	200	2000-2200	NS	NS	NS
1983	56	615	1080	1751	NS	NS	NS
1984	1000-1600	100	100-200	1200-1900	300-500	NS	300-500

Key and Information Sources:

1980 Renaud and Davis 1981 (corrections applied; see text)
1981 Davis et al. 1982
1982 Harwood and Ford 1983 (corrections applied; see text)
1983 McLaren and Davis 1985
1984 Present study
NS Not surveyed
a All estimates corrected for submerged whales and surfaced undetected whales.

Reconnaissance flights over the pack ice edge in 1983 (Cubbage et al. 1984) and systematic surveys in this area in 1984 suggest that the pack ice is not used extensively by bowheads during late August-September.

Although the overall abundance of bowheads in the southeast Beaufort Sea appears to have been relatively consistent during late August and September of the last four years, the specific locations where bowheads have congregated have varied markedly. For example, in 1980, bowheads were concentrated off the Tuktoyaktuk Peninsula (Renaud and Davis 1981). The Tuk. Pen. Zone was also used by relatively large numbers of bowheads in late August and September 1981, although the location of the specific concentration areas were different from those of the previous year (Davis et al. 1982). In a similar manner, Yukon coastal waters were used by large numbers of bowheads in August 1983 and September 1984, but to a limited extent in 1981, 1982, and September 1983.

RELATIONSHIP BETWEEN OCEANOGRAPHIC FEATURES AND BOWHEAD DISTRIBUTION -- 1984 AND PAST YEARS

1984 Summary

Summarizing the apparent relationships between bowheads observed during August and September 1984 and oceanographic features, the following patterns emerge.

Estuarine fronts north of Richards Island. In spite of a large number of incidental sightings by industry personnel in the general area of the river plume edge immediately north of Richards Island and the shallow shelf beyond, and the observation by others of at least one group of about 15 bowheads along the plume edge (Davis et al. in prep.), the 1984 systematic search indicated that relatively small numbers of bowheads were using these areas during surveys in August and September 1984.

Few animals were seen on-transect crossing the northern edge of the offshore plume where a retrograde type of front might be expected. This type of estuarine front (where the isopleths slope outwards from the coast) is usually characterized by strong salinity and density gradients. Because the large density gradients must be dynamically balanced by either vertical or horizontal water movement, friction, and mass entrainment, the character of these frontal features can vary considerably. There are many examples of physical convergence at estuarine fronts leading to local aggregation of phytoplankton (Iisuka and Irie 1969; LeFevre and Grall 1970), sardine (Tsjuita 1957), and albacore (Owen 1968). However, as described by Denman and Powell (1984), each riverine front appears to possess its own individual character, which may depend in large measure upon the preceding meteorological conditions. This variability may, in part, explain the observed fluctuation in the number of bowheads along the Mackenzie plume during the last five years.

Upwelling fronts along the Yukon Coast. In contrast to the small number of individuals or groups using the outer edge of the river plume in 1984, large congregations of bowheads were found along the western edge of the river plume and off the Yukon coast when wind-driven water movements favoured upwelling, prograde fronts in that region. Most were on the colder, clearer side of the sharpest thermal and turbidity gradients (see Figure 21). Large numbers of bowheads were present at this type of front at this location in 1983 (Borstad 1985a). In general, the complicated bottom topography (steeply sloping bottom close to the coast, and the presence of Herschel Canyon and of islands and promontories) probably magnifies the heterogeneity of this region.

Thermal fronts on the Tuktoyaktuk Shelf. In late August, the outer edge of the Tuktoyaktuk Shelf exhibited thermal gradients similar to those in the bowhead concentration areas, yet no whales were observed on systematic surveys crossing this area. The nature of these fronts is unclear. However, it may be significant that this area was ice-covered during much of July and early August. During both the August and September surveys, the shallow waters over the shelf area itself were relatively homogeneous with respect to both temperature and turbidity. Except for the convergent front along the eastern side of the eddy seen on 11 and 12 September, there were no thermal gradients greater than 0.5°C/km in waters less than 50 m in depth.

Cape Bathurst and Franklin Bay. Large numbers of bowheads were also observed in the vicinity of Cape Bathurst and in Franklin Bay during surveys in both August and September. Satellite imagery indicates complicated and vigorous surface water movements in these areas during both periods. No coincident imagery is available for comparison, but airborne observations showed that half (9 of 18) of the animals sighted on 23 August were located near visible discontinuities, or ice strings that mark temporary surface convergences. It may also be important to note that the Franklin Bay congregation was located over the end of a submarine canyon, where it rises abruptly to the coast. Subsurface flow in such a region could also be expected to be complex, and local upwelling is a possibility.

General Trends

Following the reasoning that bowheads must feed on local concentrations of zooplankton, and that zooplankton are often, but not always, found in greater abundance at physical discontinuities, a sketch map of geographic areas often showing physical features that appear to have some importance to bowheads has been prepared. Figure 22 shows the generalized geographical distribution of several common physical phenomena that can be seen in NOAA 7 AVHRR imagery. This highly generalized and simplified picture *is only* an attempt to represent areas of higher probable abundance of zooplankton and will be modified by physical and biological events in any one year. Because zooplankton growth and reproduction in the Arctic is closely synchronized with phytoplankton blooms, several factors will presumably be important on regional or local scales including:

- timing and geographical extent of ice break-up and pack movements
- overall cloud cover affecting available light during the open water months
- vertical movements of water that can alleviate nutrient depletion for phytoplankton in certain regions.

Physical processes like advection and convergence will interact with biological factors such as reproduction, growth, vertical migration, and behaviour to modify the distribution of zooplankton. Thus, there is no reason to expect zooplankton to be equally abundant throughout the region or at all discontinuities. In summary, the physical and biological properties of the front (its character) are probably more important than the size of the front.

Factors determining the character of oceanographic fronts operate on a variety of time and space scales, but the small-scale features that last for a few hours or days are probably less important to bowheads than larger and more long-lasting events. If food abundance were the major factor influencing bowhead movements (probably an over-simplification), the largest bowhead aggregations would be expected in regions that have the largest, most-sustained zooplankton supply, whereas other geographic regions would support only small numbers of scattered individuals. Thus, the character of the front or discontinuity is believed to play a major role in determining its potential for attracting bowheads (e.g., Gallardo et al. 1983). Over the long term, the Herschel Island and Yukon coast and the Cape Bathurst and Franklin Bay areas seem to be important, both in terms of the types of surface oceanographic features observed there, and the documented abundance of bowheads. The large area over the Tuktoyaktuk Shelf and along the Mackenzie plume (including the industry zone) appears to have a more variable attractiveness to bowheads. At least some of the physical phenomena that appear to influence bowhead distribution can now be recognized in satellite imagery. Work is in progress on a conceptual model linking wind regime, plume movements, and whale numbers, and this model may be of some predictive value (Davis et al. in prep.).

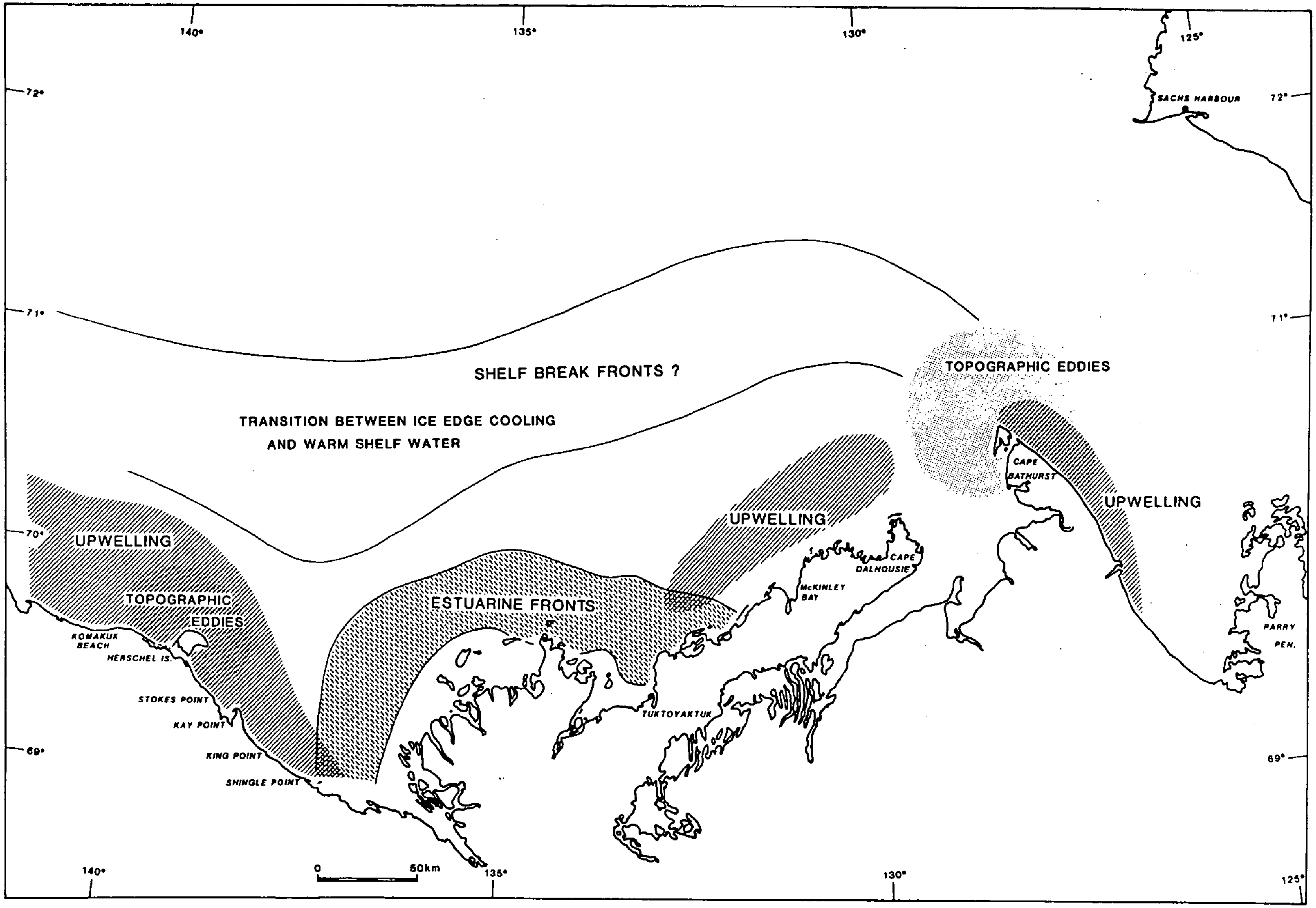


Figure 22. Distribution of major oceanographic features in the southeast Beaufort Sea during late summer.

RELATIONSHIP BETWEEN INDUSTRIAL ACTIVITY AND BOWHEAD DISTRIBUTION -- 1984 AND PAST YEARS

Bowheads have been observed in the vicinity of industrial activity in the southeast Beaufort Sea during 1980-1984 systematic surveys and by industry and support personnel (Renaud and Davis 1981; Davis et al. 1982; Harwood and Ford 1983; McLaren and Davis 1985). The industrial development zone was used extensively by bowheads during late August 1980, the first year of the systematic surveys. Subsequent surveys have also indicated the presence of bowheads in the Delta and west Tuk. Pen. zones (primary industrial area), although numbers of whales were considerably lower than those found in the 1980 surveys. In the absence of information concerning all factors influencing bowhead distribution, however, this finding should not be interpreted as a trend toward decreasing use of the industry zone by bowheads. Yukon coastal waters were used extensively by bowheads at times in 1983 and 1984, but apparently not in 1981 or 1982. Without a better understanding of the natural factors influencing bowhead distribution, it cannot be concluded that bowhead use of Yukon coastal waters is increasing. Bowhead distribution appears to vary markedly among and within years, both in areas where industrial activity occurs, and in areas outside of the industrial zone. A retrospective examination of the oceanographic features of 1980-1983 bowhead concentration areas (Davis et al. in prep.) should provide essential information regarding the reasons for the apparent variability in the use of certain areas by bowheads.

The results of the present study and Borstad (1985a) suggest that physical and biological oceanographic factors probably have a significant influence on bowhead distribution in this region. This conclusion is based on the 1983 and 1984 findings that bowheads tends to congregate near oceanographic features that often attract or concentrate zooplankton in other regions. Although this study lends support to the hypothesis that the observed variability in bowhead distribution is related to food availability, it cannot invalidate the alternate hypothesis that industry activities may be excluding whales from certain areas. To confirm the link between whale distribution and oceanographic features identifiable in satellite imagery, in situ sampling of the relative density of zooplankton at the fronts where whales feed and congregate would be required.

<u>APPENDIX 1</u>

Locations of Survey Transects and Survey Dates

APPENDIX 1

TABLE A-1. Locations of survey transects and survey dates, late August 1984

Late August 1984

Transect no.	Zone	Survey date (August 84)	Longitude (°W)	Latitude (°N) South	Latitude (°N) North	Transect length (km)
1	Yukon	27	140° 42.9'	69° 37.2'	71° 30'	209
2		27	140° 11.9'	69° 36.2'	71° 30'	211
3		27	139° 39.8'	69° 35.1'	71° 00'	157
4-N		27	139° 07.7'	69° 50.0'	71° 00'	130
5-N		27	138° 37.0'	69° 42.0'	71° 50'	237
6		27	138° 06.5'	69° 08.5'	71° 50'	299
7		18	137° 34.7'	69° 40.2'	71° 30'	203
8	Delta	18	137° 02.8'	69° 02.2'	71° 30'	274
9		18	136° 31.1'	69° 17.1'	71° 05'	200
10		18	136° 00.0'	69° 29.1'	71° 05'	177
13		22	134° 24.5'	69° 44.2'	71° 50'	233
14		22	133° 53.9'	69° 39.5'	71° 50'	242
15		22	133° 23.2'	69° 38.1'	71° 59.2'	261
16	Tuk.	22	132° 50.8'	69° 39.5'	72° 00'	260
17	Pen.	22	132° 19.9'	69° 48.8'	72° 05'	252
18		22	131° 47.9'	69° 51.6'	72° 05'	247
19		22	131° 17.2'	70° 00.0'	72° 20'	259
20		22	130° 46.1'	70° 10.9'	72° 20'	239
21		23	130° 14.9'	70° 10.2'	71° 20'	129
22		23	129° 42.1'	70° 16.9'	71° 20'	117
23		23	129° 09.8'	70° 03.2'	71° 22.4'	147
24		23	128° 39.9'	69° 51.2'	71° 25'	174
25-N	West	23	128° 08.8'	70° 40.7'	71° 35.5'	101
26-N	Amundsen	23	127° 34.2'	70° 49.0'	71° 35.0'	85
27		23	127° 03.2'	70° 10.0'	72° 00'	204
28-N		23	126° 33.8'	70° 00.0'	72° 00'	222

TABLE A-1 (Continued)

Transect no.	Zone	Survey date (August 84)	Longitude (°W)	Latitude (°N) South	Latitude (°N) North	Transect length (km)
3c	Herschel	27	139° 21.2'	69° 34'	69° 50'	29.6
3d		27	139° 15.0'	69° 36.5'	69° 50'	25.0
4-S		27	139° 07.7'	69° 38.0'	69° 50'	22.2
4a		27	139° 01.5'	69° 38.0'	69° 50'	22.2
4b		27	138° 55.3'	69° 37.0'	69° 50'	24.1
4c		27	138° 49.1'	69° 23.5'	69° 40'	30.6
4d		27	138° 42.9'	69° 21.5'	69° 40'	34.3
5-S		27	139° 37.0'	69° 18.6'	69° 42'	43.3
5a		27	138° 30.8'	69° 16.5'	69° 42'	47.2
5b		27	138° 24.6'	69° 18.3'	69° 42'	43.9
5c		27	138° 18.4'	69° 16.5'	69° 42'	47.2
5d		27	138° 12.2'	69° 10.5'	69° 42'	58.3
24a	Baillie	23	128° 29.6'	70° 30.0'	70° 42.9'	23.9
24b		23	128° 19.3'	70° 39.6'	70° 43.0'	6.3
25-S		23	128° 08.8'	70° 30.6'	70° 40.7'	18.7
25a		23	127° 57.2'	70° 32.0'	70° 47.0'	27.8
25b		23	127° 45.7'	70° 32.2'	70° 48.8'	30.7
26-S		23	127° 34.2'	70° 26.1'	70° 49.0'	42.4
28-S	Franklin	23	126° 33.8'	69° 40'.3	70° 00'	36.5
28a		23	126° 27.6'	69° 40'	70° 00'	37.0
28b		23	126° 21.4'	69° 40'	70° 00'	37.0
28c		23	126° 15.2'	69° 40'	70° 00'	37.0
28d		23	126° 09.0'	69° 40'	70° 00'	37.0

TABLE A-1 (Continued)
September 1984

Transect no.	Zone	Survey date (Sept. 84)	Longitude (°W)	Latitude (°N) South	Latitude (°N) North	Transect length (km)
1	Yukon	6	140° 42.9'	69° 37.2'	71° 30'	209
2		6	140° 11.9'	69° 36.2'	71° 30'	211
3		11	139° 39.8'	69° 35.1'	71° 20'	194
4		11	139° 07.7'	69° 38.0'	71° 20'	189
5		11	138° 37.0'	69° 18.6'	71° 20'	225
6		11	138° 06.5'	69° 08.5'	71° 21'	245
7		11	137° 34.7'	69° 02.2'	71° 40'	292
8	Delta	11	137° 02.8'	69° 02.2'	71° 40'	292
9		11	136° 31.1'	69° 17.1'	71° 40'	265
10		11	136° 00.0'	69° 29.1'	71° 40'	242
11		11	135° 28.7'	69° 39.6'	71° 10'	167
12		11	134° 57.2'	69° 41.7'	71° 10'	164
13		11	134° 24.5'	69° 44.2'	71° 20'	177
14		11	133° 53.9'	69° 39.5'	71° 20'	186
15		12	133° 23.2'	69° 38.1'	70° 55'	142
16	Tuk.	12	132° 50.8'	69° 39.5'	70° 55'	140
17	Pen.	12	132° 19.9'	69° 48.8'	70° 34'	121
18		12	131° 47.9'	69° 51.6'	70° 30'	71
19		17	131° 17.2'	70° 00.0'	71° 40'	185
20		17	130° 46.1'	70° 10.9'	71° 40'	165
21		17	130° 14.9'	70° 10.2'	71° 40'	166
22		17	129° 42.1'	70° 16.9'	71° 40'	154
23		13	129° 09.8'	70° 03.2'	71° 50'	198
24		13	128° 39.9'	69° 51.2'	71° 50'	220
25	West	13	128° 08.8'	70° 30.6'	71° 20'	91
26	Amundsen	13	127° 34.2'	70° 26.1'	71° 40'	100
27		18	127° 03.2'	70° 10.0'	71° 00'	93
28		18	126° 33.8'	69° 40.3'	71° 00'	148
29		18	126° 02.8'	69° 25.8'	70° 13'	87

TABLE A-1 (Continued)
12 September 1984 reconnaissance survey along thermal front

	(°N Latitude)	(°W Longitude)
Starting position	69° 51.6'	131° 47.9'
Position A	70° 00'	132° 00'
B	70° 25'	131° 48'
C	70° 10'	132° 35'
D	70° 20'	132° 50'
E	70° 05'	133° 23'
F	70° 00'	133° 00'
Ending position	70° 00'	132° 50'

APPENDIX 2

Size of Study Area and Per cent Survey Coverage

APPENDIX 2

TABLE A-2. Size of study area and per cent survey coverage, km^2 surveyed (per cent survey coverage)

1984 Survey period	Strata [a]			
	Yukon	Delta	Tuk. Pen.	West Amundsen
5-9 July	11,800 (3.2)	24,300 (9.7)	10,400 (7.8)	NS
13-18 July	23,400 (3.5)	28,200 (4.3)	11,800 (5.0)	NS
21-23 July	20,000 (6.1)	25,400 (6.3)	19,100 (5.4)	NS
28 July-2 Aug.	38,300 (3.5)	10,300 (3.6)	21,900 (4.7)	NS
18-27 Aug.	28,440 (10.2)	32,600 (8.4)	37,400 (9.7)	12,370 (9.7)
	Herschel 1,750 (49.0)			Baillie 1,090 (29.6)
				Franklin 740 (50.0)
6-18 Sept.	29,600 (10.4)	30,600 (10.5)	26,200 (9.9)	9,600 (10.8)

[a] All stratum boundaries fixed among surveys except north endpoints, which reflect only latitudes reached during surveys.

Shoreward boundary 2-m isobath in all cases.

Based on transect width of 2 km.

NS = not surveyed

APPENDIX 3

Effective Transect Width

APPENDIX 3

EFFECTIVE TRANSECT WIDTH

The strip transect method used for these surveys assumes equal detectability of all surfaced animals throughout the width of the 2-km transect strip. This section describes results obtained to evaluate if this assumption was met.

Inclinometer readings were taken for 71 of the total 80 bowhead whale sightings made during 1984 bowhead surveys. The lateral distance of these sightings from the flight path was then calculated using trigonometry, and these distances plotted (Figure A-1). Overall, 52 per cent of the sightings were seen on the inner 500 m of each strip, and 48 per cent were seen on the outer 500-m portion. These percentages suggest that the assumption of equal detectability was met.

However, Figure A-1 illustrates that the distribution of sightings was bi-modal (peaks in the 200-400-m range and in the 700-900-m range). Whales in the 400-700-m range may have been missed by observers more often than whales at the outer and inner edges of the strip or they may have surface less frequently. The data on Figure A-1 represent sightings made by six different observers, with varying degrees of recent (e.g., 1984) and previous (e.g., past years) survey experience. When sightings for each observer are plotted separately, the same general trend was not apparent.

It is believed that the lower numbers apparently recorded in the middle of the strip were probably as a result of measurement error. The precision of the inclinometer method was not investigated in this study, but may be as high as $\pm 3^\circ$ in some cases. The reading must be taken from the horizontal, and this is affected by the pitch of the aircraft and head position of the observer. The approximate inclinometer readings that correspond to distances from the flight path are also shown on Figure A-1. While an error of $\pm 3^\circ$ translates to less than 100 m on the inner portions of the strip, it could be 100-300 m at distances 600 m from the flight path. Therefore, measurement error (particularly in the outer strip) may have been responsible for the trends in Figure A-1.

If, in fact, the assumption of equal detectability were not met because of reduced detectability mid-strip, the abundance estimates would then be conservative. At the same time, on the outer 200 m of the strip, measurement errors of $\pm 3^\circ$ could have led to the inaccurate assignment of on- or off-transect status to some whales. Depending on the direction of the error, abundance estimates could have been overestimated (off-transect assigned as on-transect) or underestimated (on-transect assigned as off-transect). Because the potential for such errors is presumably equal in either direction, these biases probably offset each other.

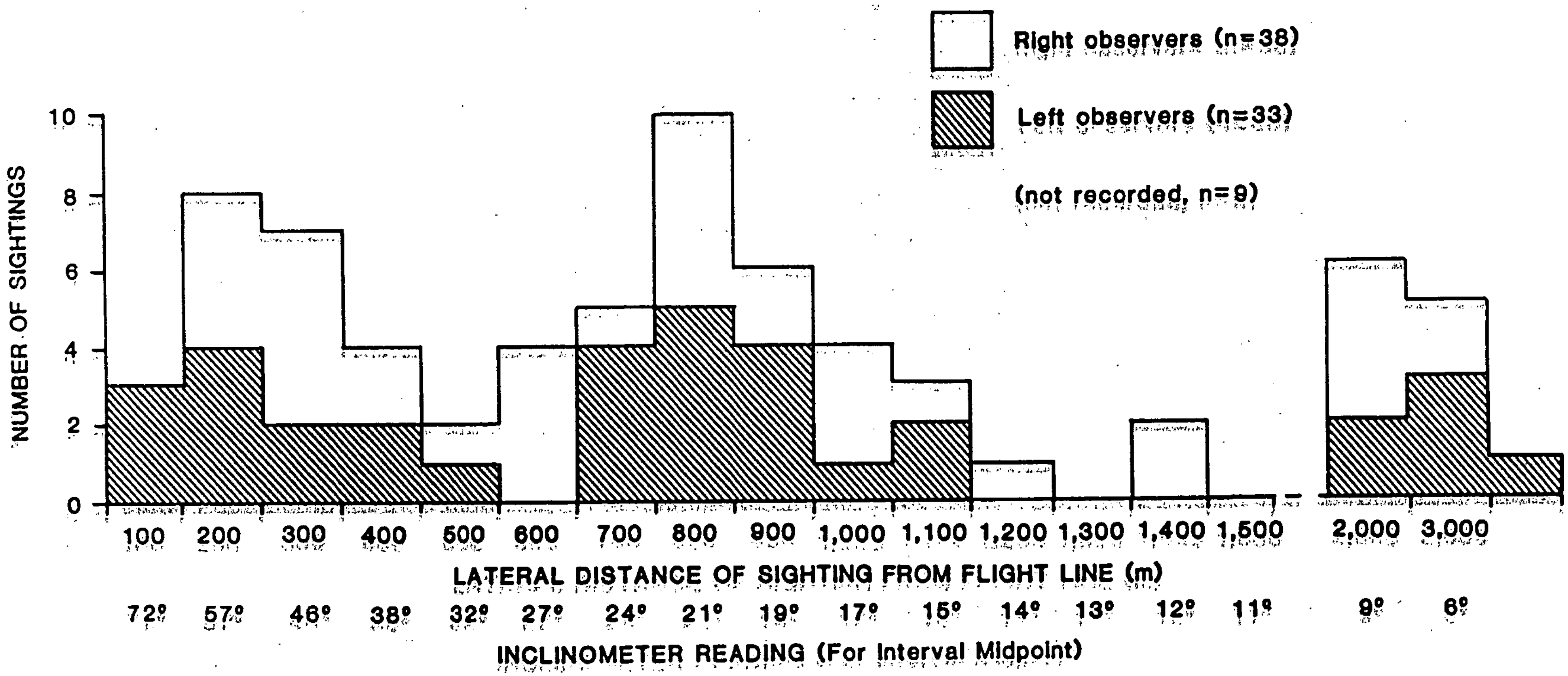
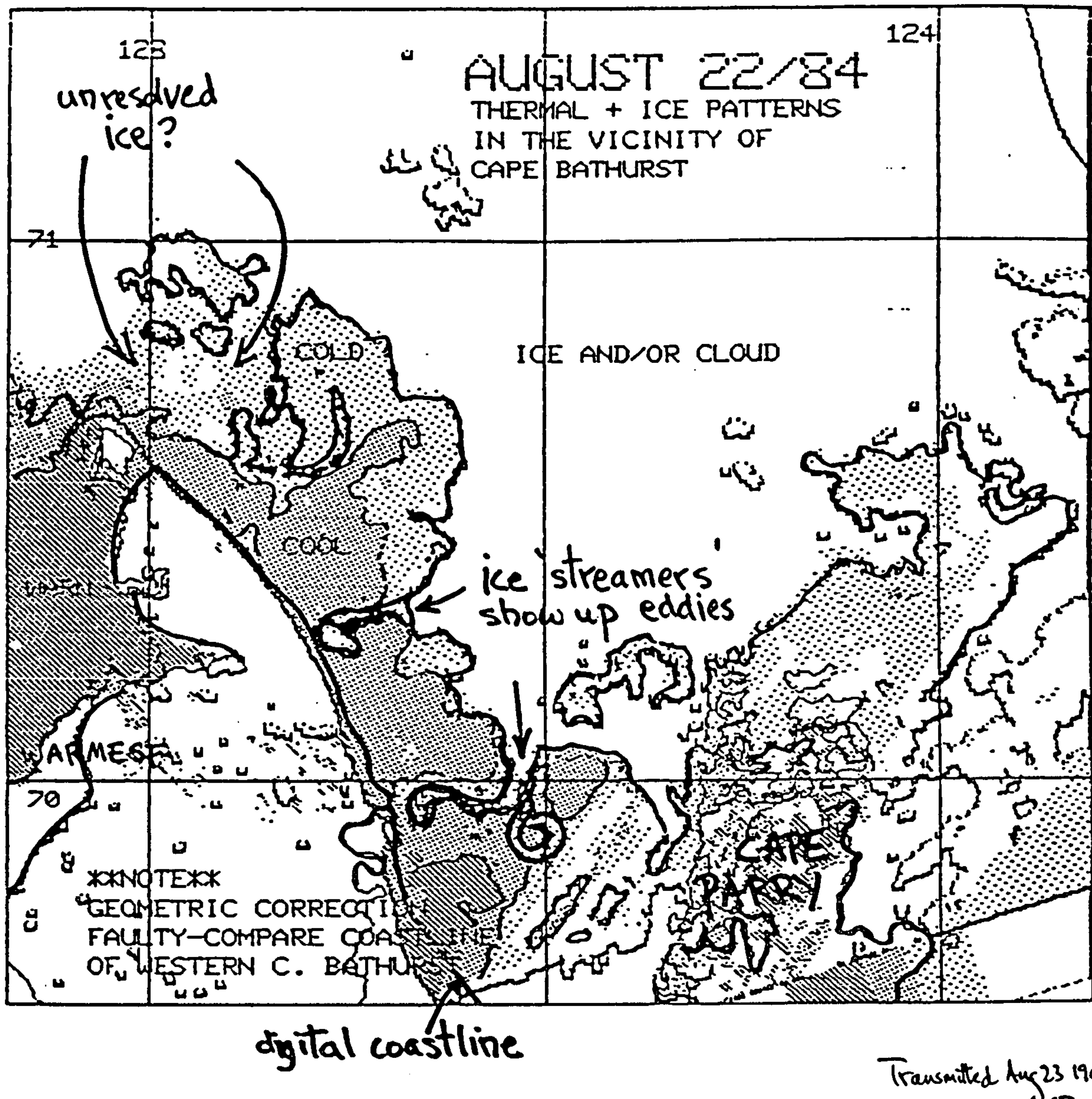


Figure A-1. Frequency distribution of lateral distance from flight line of bowhead whale sightings, August-September 1984.

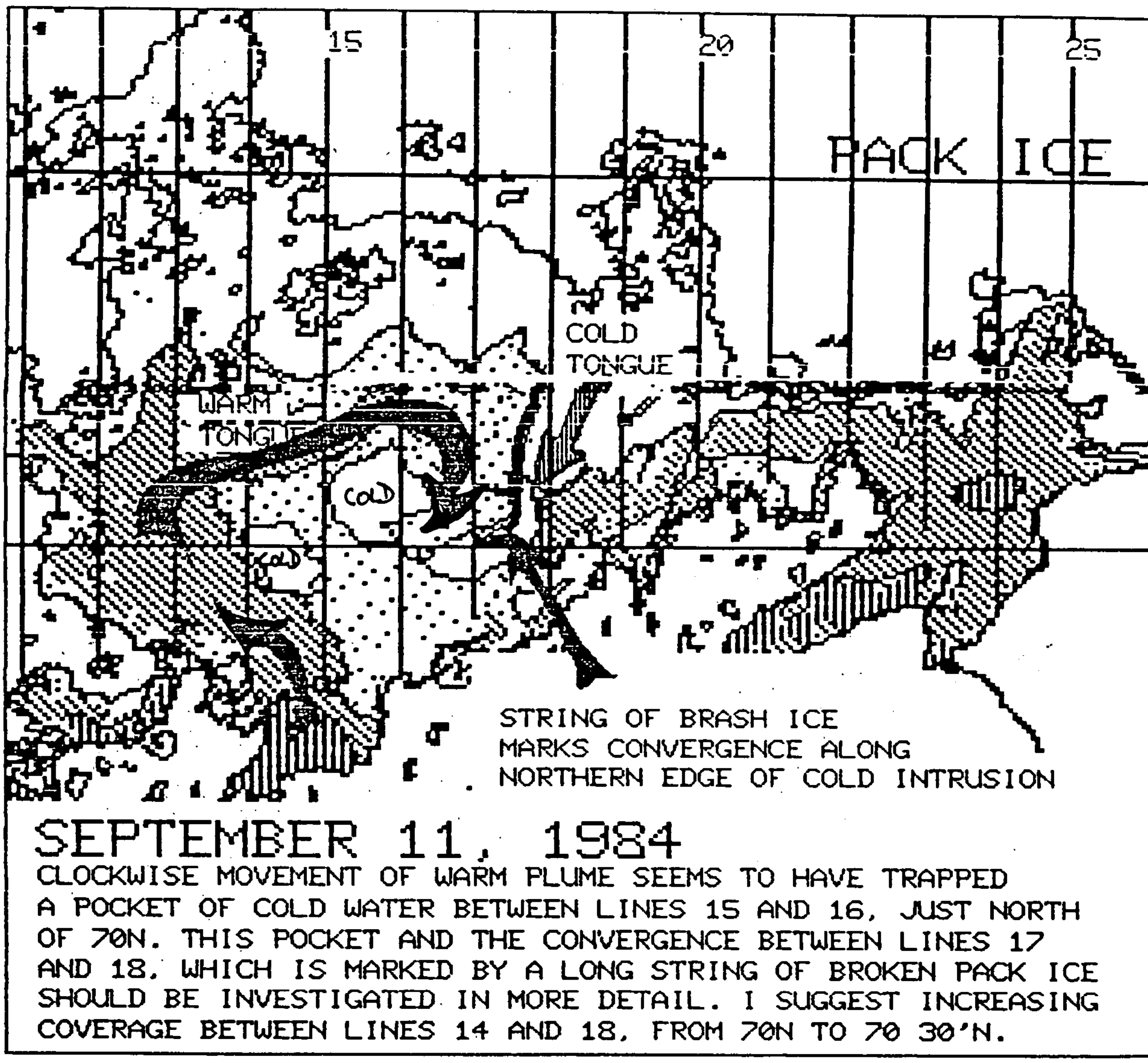
APPENDIX 4

Examples of Satellite Imagery Analyses
Transmitted to Field Crew



Transmitted Aug 23 1900PDT
GB

Figure A-2. Thermal and ice patterns in the vicinity of Cape Bathurst, 22 August 1984.



Transmitted Sept 12, 84

Figure A-3. Thermal and ice patterns offshore of Tuktoyaktuk Peninsula, 11 September 1984.

APPENDIX 5

Seal and Walrus Sightings Recorded
Incidentally during Bowhead Survey and
by Industry Personnel

APPENDIX 5

SEAL AND WALRUS SIGHTINGS RECORDED INCIDENTALLY DURING BOWHEAD SURVEYS AND BY INDUSTRY PERSONNEL

A5.1 Aerial Survey Results

Ringed and bearded seals are the only common pinnipeds in the Canadian Beaufort Sea region, and were frequently recorded during the late August and September surveys. About 150 ringed seals were seen on the 18-27 August survey, and all were on-transect. An additional 36 ringed seals were seen incidentally to the transect surveys. Four bearded seals were recorded on-transect during the late August survey, and none were recorded incidentally.

Twenty-six ringed seals were seen during the 6-18 September survey, and all sightings were on-transect. An additional nine ringed seals were seen incidentally to the systematic surveys. Four bearded seals were recorded on-transect. The locations of seals sighted during the late August and September surveys are shown on Figures A-4, and A-5, respectively, along with coincident ice conditions and industrial activity. Seabirds associated with seal sightings are also indicated.

The detectability of ringed and bearded seals is affected by survey conditions and seat position to an even greater extent than detectability of bowheads. Seals are most easily detected in areas with calm seas (e.g., Beaufort Scale 0-2) and where there is no glare ("excellent conditions"). Furthermore, even in areas where survey conditions are excellent, seals are not equally detectable throughout the 2-km wide transect strip. In 1984 surveys, seal detectability decreased markedly at a distance of 200 to 400 m from the flight path, depending on sea state and seal group size. The locations in Figures A-4 and A-5 where seals were observed reflect some (but not all) areas surveyed under excellent survey conditions. Comparable numbers of seals may have occurred in other portions of the study area, but were not detected.

A5.2 Observations by Industry Personnel

Seal and walrus sightings recorded by ice observers and industry personnel on support vessels and facilities operated by or on behalf of Dome Petroleum Limited have been reviewed for the present study. These data are limited by weather conditions and by variable levels of experience of observers, but do provide a useful supplement to the data collected during systematic surveys. In many instances, the species was not identified so bearded and ringed seal sightings have been combined. Some sightings may have been duplicated over consecutive watch periods by observers on a stationary support vessel.

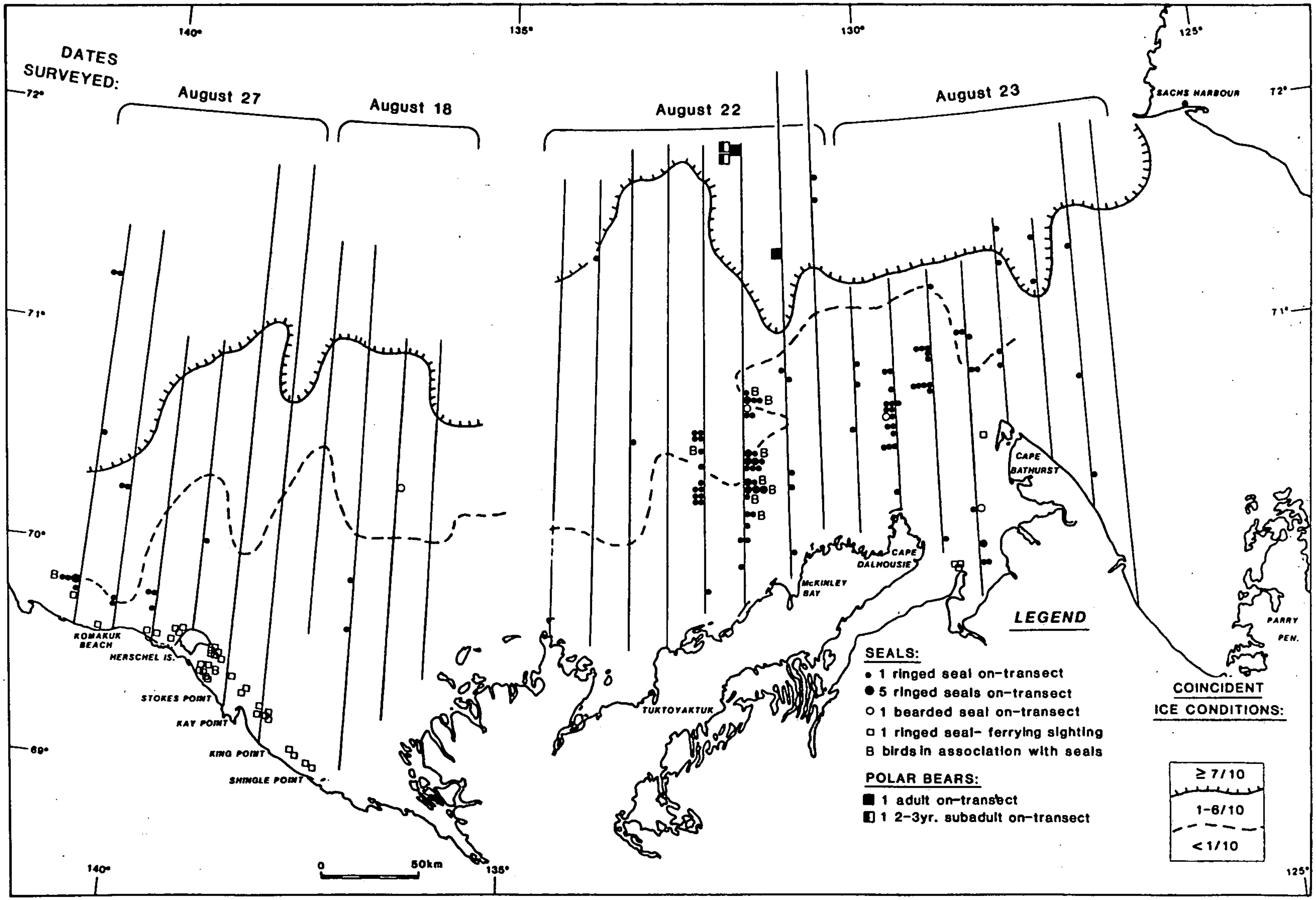


Figure A-4. Seals and polar bears sighted during systematic surveys for bowhead whales in the southeast Beaufort Sea, 18-27 August 1984.

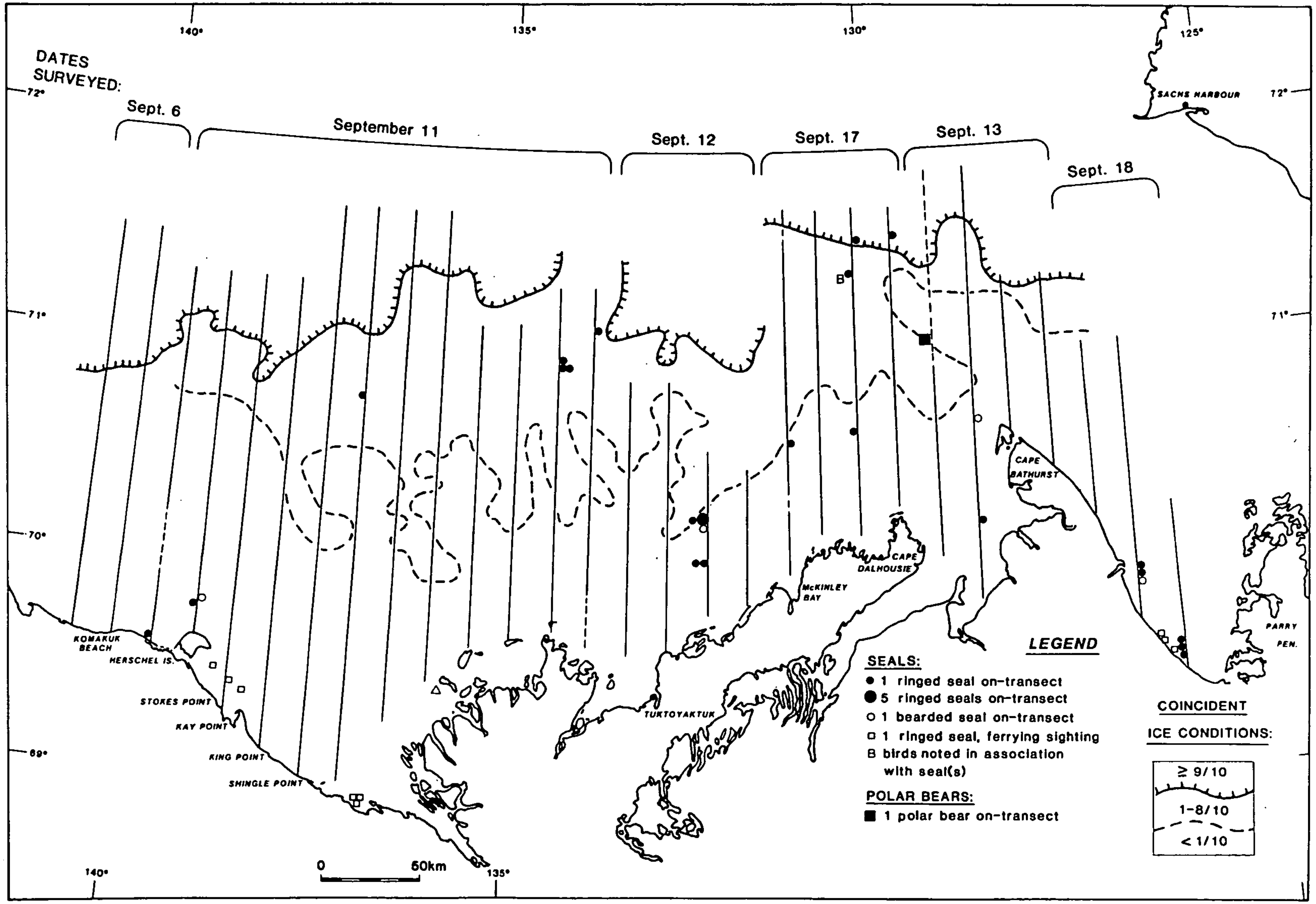


Figure A-5. Seals and polar bears sighted during systematic surveys for bowheads in the southeast Beaufort Sea, 6-18 September 1984.

Over 2200 seals were recorded by industry personnel during the open-water period. The majority of sightings were between 131° and 137°W longitude, because this area was where most industrial activity was centered in 1984. Seals were reported at Aiverk, Natiak, McKinley Bay, Kugmallit Bay, Havik, Kogyuk, Arluk, Siuluk and Wise Bay (locations on Figure 10. Areas where seals were recorded by industry personnel correspond to some portions of the study area where seals were not detected on the systematic surveys.

There were two walrus sightings reported by industry personnel in 1984. One (tusked) individual was clearly a walrus (23 September at Siuluk), while the other (15 July near Kogyuk) may have been a bearded seal.

TABLE A-3

Seal sightings reported by industry personnel, 1984

Vessel type	No. of vessels with reports	Total no. of seals sighted	Sighting dates (first and last)	Per cent of total seals sighted
Drillships	4	745	28 June-20 Oct.	32.8
Icebreakers	2	739	10 June-16 Oct.	32.5
Supply	7	512	3 July-20 Oct.	22.5
Support	5	268	17 June-14 Oct.	11.8
Fuel Storage	1	8	18-26 May	0.4
Total		2272		

A5.3 Comments

Substantial portions of the Yukon Zone were sampled when survey conditions were excellent during both surveys in late August and September. Consequently, the probability of detecting seals at the surface in these waters was considered high. Ringed seals were common in Yukon coastal waters, and were often noted in association with seabirds and bowheads. It is not known if the lower number observed in September in the Yukon Strata reflects an actual movement of seals from the zone.

As indicated in Figure A-4, seals were relatively abundant offshore of the Tuktoyaktuk Peninsula during late August and in Franklin Bay during September. The presence and activities of seabirds and bowheads in the vicinity of some of the large groups of ringed seals (Figure A-4 and A-5) suggests that they may have been feeding on a common prey. These same areas were not surveyed under excellent conditions in September and late August, respectively, so it is not known if seal numbers were comparable among surveys.

Few seals were recorded in the Delta Zone and in offshore Yukon Zone, despite the fact that survey conditions were excellent in many areas (Figures A-4 and A-5). These results suggest that the offshore Yukon Zone and Delta Zone may have been less important for seals during late summer 1984 than Yukon coastal waters or areas offshore of the Tuktoyaktuk Peninsula (where large groups were observed and were apparently feeding). At the same time, however, industry personnel frequently observed seals in the Delta Zone during 1984.

APPENDIX 6

Polar Bear Sightings Recorded Incidentally during Systematic Surveys for Bowheads and by Industry Personnel

APPENDIX 6

POLAR BEAR SIGHTINGS RECORDED INCIDENTALLY DURING SYSTEMATIC SURVEYS FOR BOWHEADS AND BY INDUSTRY PERSONNEL

A6.1 Aerial Survey Results

A total of four polar bears was recorded during the 18-27 August systematic surveys (Figure A-4). One sighting was of a single adult, while the other was an adult with two 2-3 year olds. All of these bears were observed in an area of 9/10 concentration ice. During the 6-18 September survey, an immature polar bear was observed in an area of 3/10 concentration ice (Figure A-5).

A6.2 Sightings by Industry Personnel

During the period from 1 July through 21 October, industry personnel in the Beaufort region reported 106 polar bear sightings (170 animals including 43 cubs or subadults. Information on these sightings is provided in Table A-4. Most sightings were reported from vessels operating in the area bounded by 70° to 70°40'N latitude and 131° to 137°W longitude (the drilling zone). Some of the sightings may have been repeat observations of the same bear(s).

A6.3 Comments

The number of polar bears sighted in the southeast Beaufort Sea during summer and fall 1984 was relatively high compared with previous years (e.g., 3 and 37 reported by industry personnel in 1982; and 1983, respectively). This is likely because opportunities for observing bears were greater in 1984 because of the position of the pack-ice; ice was present in the hydrocarbon exploration zone throughout July, August, and most of September.

TABLE A-4

Polar bear sightings reported by industry personnel in 1984

Vessel type	No. of vessels with reports	Total bears sighted (no. of cubs or subadults)	Total sightings	Approximate sighting locations[a]
Drillship	4	26 (2)	18	Siuluk, Aiverk, Havik, Arluk
Icebreaker	2	67 (22)	39	Between 70°-70°40'N and 132°13'-137°21'W
Supply	7	61 (15)	41	Siuluk, Arluk, Kogyuk, Aiverk, Havik, Natiak, between 70°00'-70°40'N and 131°-135°W
Support	3	16 (4)	8	Aiverk, between 70°10' - 70°20'N and 132°-135°W
Total		170 (43)	106	

[a] See Figure 10 in text.

REFERENCES

Aiken, J. 1981. Data presented during summing up discussion of the circulation and fronts in continental shelf seas. p. 688-689. In: K.F. Bowden, Summing Up. Philosophical Transactions of the Royal Society of London, Series A, 302:683-689.

Best, P.B. 1967. Distribution and feeding habits of baleen whales off Cape Province. South Africa Division of Fisheries Investigative Report 57:1-44.

Borstad, G.A. 1985a. Water colour and temperature in the southern Beaufort Sea: remote sensing in support of ecological studies of the bowhead whale. Canadian Technical Report on Fisheries and Aquatic Sciences 1350. 69 p.

Borstad, G.A. 1985b. Analysis of satellite digital imagery in support of DFO oceanographic operations in the Beaufort Sea. Unpublished Report by G.A. Borstad Ltd. to Department of Fisheries and Oceans, Winnipeg. 10 p.

Breiwick, J.M., E.D. Mitchell, and D.G. Chapman. 1981. Estimated initial population size of the Bering Sea stock of bowhead whale, (Balaena mysticetus): an iterative method. U.S. Fish Bulletin 78(4):843-853.

Caughley, G. 1977. Sampling in aerial survey. Journal of Wildlife Management 41(4):605-615.

Cubbage, J.C., J. Calambokidis, and D.J. Rugh. 1984. Bowhead whale length measured through stereophotogrammetry. Prepared by Cascadia Research Collective, Olympia, Washington. Prepared for National Marine Mammal Laboratory, Seattle, Washington. 71 p.

Davis, R.A., W.R. Koski, W.J. Richardson, C.R. Evans, and W.G. Alliston. 1982. Distribution, numbers and productivity of the western Arctic stock of bowhead whales in the eastern Beaufort Sea and Amundsen Gulf, summer 1981. Prepared by LGL Limited, Toronto, Ontario. Prepared for Dome Petroleum Limited, Calgary, Alberta, and Sohio Alaska Petroleum Company, Anchorage, Alaska. 135 p.

Davis, R.A., D.H. Thomson, D.B. Fissel, J.R. Marko, and G.A. Borstad. (in prep). The factors determining bowhead whale distribution in the Beaufort Sea: a feasibility study. Draft Report prepared by LGL Ltd., Arctic Sciences Ltd. and G.A. Borstad Ltd. Prepared for Environmental Studies Revolving Funds and Indian and Northern Affairs Canada.

Denman, K.L. and T.M. Powell. 1984. Effects of physical processes on planktonic ecosystems in the coastal ocean. Oceanography and Marine Biology; An Annual Review 22:125-168.

Eberhardt, L.L., D.G. Chapman, and J.R. Gilbert. 1979. A review of marine mammal census methods. Wildlife Monograph No. 63. 46 p.

FEARO (Federal Environmental Assessment Review Office). 1984. Beaufort Sea hydrocarbon production and transportation. Report of the Environmental Assessment Panel, No. 25. 146 p.

Floodgate, G.D., G.E. Fogg, D.A. Jones, K. Lochte and C.M. Turley. 1981. Microbiological and zooplankton activity at a front in Liverpool Bay, Nature 290:133-136.

ESL Environmental Sciences Limited, LGL Ltd., ESSA Ltd., Arctic Laboratories Ltd., and Arctic Sciences Ltd. 1985. Beaufort Environmental Monitoring Project, 1984-1985. Draft Report. Prepared for Indian and Northern Affairs Canada, and for Environment Canada.

Gallardo, V.A., D. Arcos, M. Salamanca, and L. Pastene. 1983. On the occurrence of Bryde's whales (Balaenoptera edeni, Anderson, 1878) in an upwelling area off central Chile. International Whaling Commission. Report 33:481-488.

Gaskin, D.E. 1976. The evolution, zoogeography and ecology of Cetacea. Oceanography and Marine Biology; An Annual Report 14:247-346.

Grainger, E.H. 1975. Biological productivity of the southern Beaufort Sea: the physical-chemical environment and the plankton. Beaufort Sea Project Technical report No. 12a, Environment Canada, Victoria, B.C. 22 p.

Griffiths, W.B. and R.A. Buchanan. 1982. Characteristics of bowhead feeding areas. p. 347-455. In: W.J. Richardson (ed.), Behaviour, disturbance responses and feeding of bowhead whales Balaena mysticetus in the Beaufort Sea, 1980-81. Prepared by LGL Ecological Research Associates Inc., Bryan, TX. Prepared for U.S. Bureau of Land Management, Washington, D.C. 456 p.

Hamner, W.M. and I.R. Hauri. 1981. Effects of island mass: water flow and plankton pattern around a reef in the Great Barrier Reef Lagoon, Australia. Limnology and Oceanography 26:1084-1102.

Harwood, L.A. and J.K.B. Ford. 1983. Systematic aerial surveys of bowhead whales and other marine mammals in the southeastern Beaufort Sea, August-September 1982. Prepared by ESL Environmental Sciences Limited, Sidney, B.C. Prepared for Dome Petroleum Limited and Gulf Canada Resources Inc., Calgary, Alberta. 70 p.

Hazard, K.W. and J.C. Cubbage. 1982. Bowhead whale distribution in the southeastern Beaufort Sea and Amundsen Gulf, summer 1979. Arctic 35(4):519-523.

Herlinveaux, R.H. and B.R. de Lange Boom. 1975. Physical oceanography of the southeastern Beaufort Sea. Beaufort Sea Project Technical Report No. 18, Environment Canada, Victoria, B.C. 97 p.

Iisuka, S. and Irie, H. 1969. Anoxic status of bottom waters and occurrences of Gymnodinium re: water in Omura Bay. Bulletin Plankton Society of Japan 16:99-115.

IWC (1984). Report of the subcommittee on other protected species and aboriginal/subsistence whaling. International Whaling Commission. Report 34:131.

Leatherwood, S., K. Goodrich, A.L. Kinter, and R.M. Truppo. 1982. Respiration patterns and 'sightability' of whales. International Whaling Commission. Report 32:601-606.

LeFevre, J. and J.R. Grall. 1970. On the relationships of Noctiluca swarming off the western coast of Brittany with hydrological features and plankton characteristics of the environment. Journal of Experimental Marine Biology and Ecology 4:287-306.

LGL Environmental Research Associates, ESL Environmental Sciences Limited, and ESSA Environmental and Social Systems Analysts Limited. 1984. Beaufort Environmental Monitoring Project, 1983-84 report. Prepared for Department of Indian and Northern Affairs, and Department of Environment. 292 p.

Ljungblad, D.K., S.E. Moore, and D.R. Van Schoik. 1984. Aerial surveys of endangered whales in the northern Bering, eastern Chukchi and Alaskan Beaufort seas, 1983: with a five year review, 1979-1983. Technical Report 955. Prepared by Naval Oceans Systems Center, San Diego, California. Prepared for Minerals Management Service, U.S. Department of Interior. 119 p.

MacNeill, M.R. and J.F. Garett. 1975. Open water currents. Beaufort Sea Technical Report No. 17, Environment Canada, Victoria, B.C.

McClueny, W.R. 1975. Radiometry of water turbidity measurements. Journal of Water Pollution Control Federation 47:252-266.

McLaren, P.L. and R.A. Davis. 1985. Distribution of bowhead whales and other marine mammals in the southeast Beaufort Sea, August-September 1983. Environmental Studies Revolving Funds Report No. 001, Ottawa, Canada. Prepared by LGL Ltd., Toronto, Ontario, Canada.

Mackas, D.L., G.C. Louttit, and M.J. Austin. 1980. Spatial distribution of zooplankton and phytoplankton in British Columbia coastal waters. Canadian Journal of Fisheries and Aquatic Sciences 37:1476-1487.

Nasu, K. 1966. Fishery oceanography study on the baleen whaling grounds. Scientific Report. Whales Research Institute (Tokyo) 20:157-210.

Nemoto, T. 1959. Food of baleen whales with reference to whale movements. Scientific Report. Whales Research Institute (Toyko) 14:149-290.

Nemoto, T. 1962. Food of baleen whales collected in recent Japanese Antarctic whaling expeditions. Scientific Report. Whales Research Institute (Toyko) 16:89-103.

Nemoto T. and A. Kawamura. 1977. Characteristics of food habits and distribution of baleen whales with special reference to the abundance of north Pacific sei and Bryde's whales. International Whaling Commission. Report (Special Issue 1) 1977, p. 80-87.

Norton, P. and L.A. Harwood. 1985 White whale use of the southeastern Beaufort Sea, July-September, 1984. Canadian Technical Report on Aquatic Sciences (in press): 50 p.

Owen, R.W. 1968. Oceanographic conditions in the northeast Pacific and their relation to the albacore fishery. U.S. Fish Bulletin 66:503-526.

Owen, R.W. 1981. Fronts and eddies in the sea. p. 197-233, In: A.R. Longhurst (editor), Analysis of marine ecosystems, Academic Press, London.

Pingree, R.D., G.R. Forster, and G.K. Morrison. 1974. Turbulent convergent tidal fronts. Journal of the Marine Biological Association of the United Kingdom 54:469-479.

Pingree, R.D., P.R. Pugh, P.M. Holligan, and G.R. Forster. 1975. Summer phytoplankton blooms and red tides along tidal fronts in the approaches to the English Channel. Nature 258:672-677.

Renaud, W.E. and R.A. Davis. 1981. Aerial surveys of bowhead whales and other marine mammals off the Tuktoyaktuk Peninsula, N.W.T., August-September 1980. Prepared by LGL Limited., Toronto, Ontario, for Dome Petroleum Limited, Calgary, Alberta. 55 p.

Richardson, W.J., P. Norton, and C.R. Evans. 1984. Distribution of bowheads and industrial activity, 1983. p. 309-361, In: W.J. Richardson (ed.), Behaviour, disturbance responses and distribution of bowhead whales Balaena mysticetus in the eastern Beaufort Sea, 1983. Unpublished report by LGL Ecological Research Associates, Inc., Bryan, TX. Prepared for U.S. Minerals Managements Service, Reston, VA. 361 p.

Richardson, W.J., R.A. Davis, C.R. Evans, and P. Norton. MS. Distribution of bowheads and industrial activity, 1980-84. In: W.J. Richardson (ed.), Behaviour, disturbance responses and distribution of bowhead whales Balaena mysticetus in the eastern Beaufort Sea, 1980-84. Unpublished Report from LGL Ecological Research Association Inc. Bryan, Tx., for US Minerals Management Service, Reston, VA.

Robinson, I.S., N.C. Wells, and H. Charnock. 1984. The sea surface thermal boundary layer and its relevance to the measurement of sea surface temperature by airborne and spaceborne radiometers. International Journal of Remote Sensing 1:19-45.

Tabata, S. and J.F.R. Gower. 1980. A comparison of ship and satellite measurements of sea surface temperature off the Pacific coast of Canada. Journal of Geophysical Research 85:6636-6648.

Tsjuita, T. 1957. The fisheries oceanography of the East China Sea and Tsuchima Strait. 1. The structure and ecological character of the fishing grounds. Bulletin. Seikai Regional Fisheries Research Laboratory 13:1-47.

Würsig, B., E.M. Dorsey, W.J. Richardson, C.W. Clark, R.S. Payne, and R.S. Wells. 1984a. Normal behaviour of bowheads, 1983. p. 23-99, In: W.J. Richardson (ed.), Behaviour, disturbance responses and distribution of bowhead whales Balaena mysticetus, in the eastern Beaufort Sea, 1983. Prepared by LGL Ecological Research Association Inc., Bryan, TX. Prepared for U.S. Minerals Management Service, Reston, VA. 361 p.

Würsig, B., E.M. Dorsey, M.A. Fraker, R.S. Payne, W.J. Richardson, and R.S. Wells. 1984b. Behaviour of bowhead whales, Balaena mysticetus, summering in the Beaufort Sea: surfacing, respiration, and dive characteristics. Canadian Journal of Zoology 62:1910-1921.