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MONITORING OF THE WINTER PRESENCE OF BOWHEAD WHALES IN THE *NAVARIN BASIN* THROUGH ASSOCIATION WITH SEA ICE

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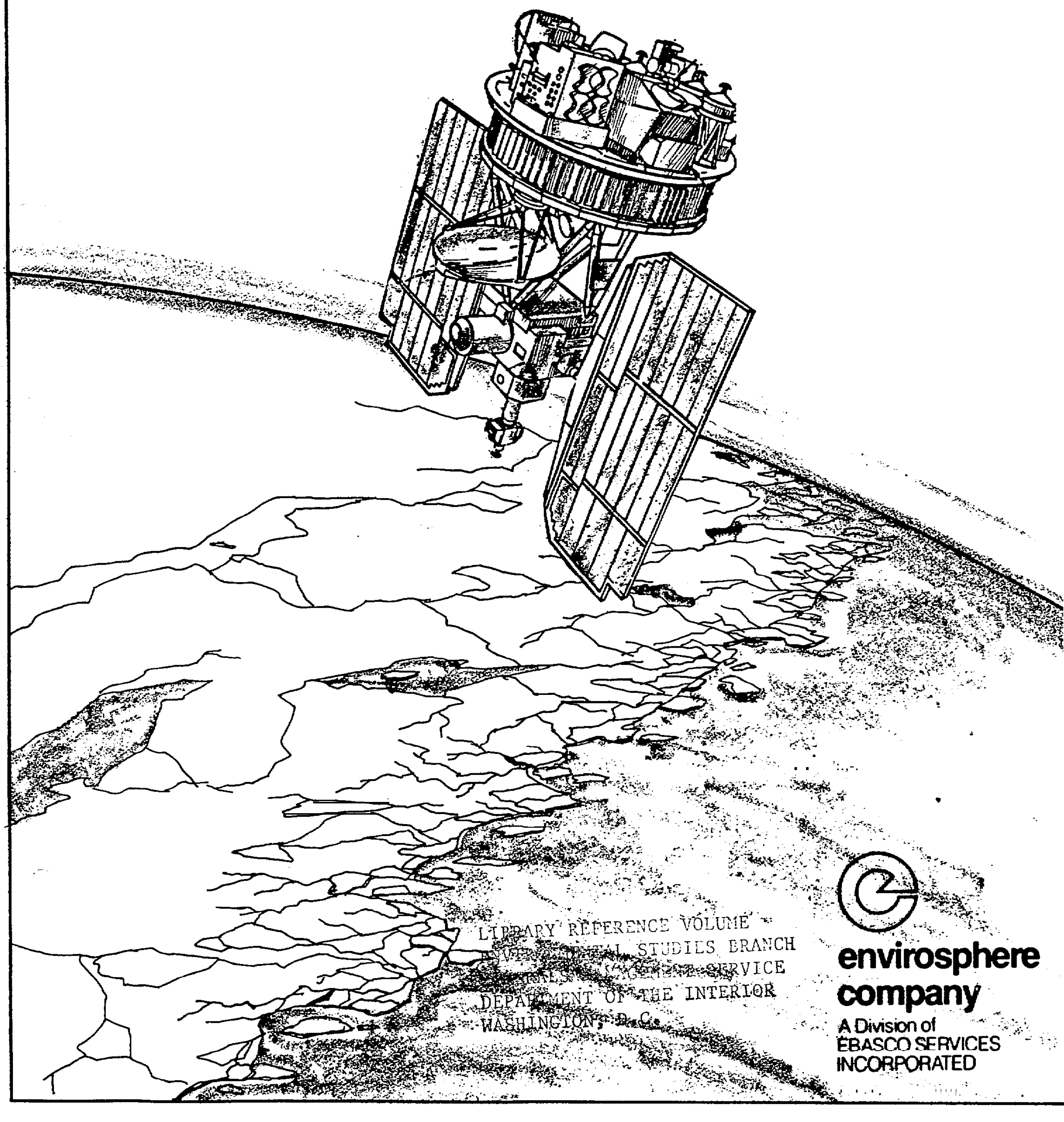

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OCS STUDY, MMS 87-0028

#711

MONITORING OF THE WINTER PRESENCE OF BOWHEAD WHALES IN THE NAVARIN BASIN THROUGH ASSOCIATION WITH SEA ICE

FINAL REPORT

Prepared by
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Prepared for
MINERALS MANAGEMENT SERVICE
U.S. Department of the Interior
Contract Number 14-12-0001-30182

JULY 1987

PROJECT ORGANIZATION AND ACKNOWLEDGMENTS

J. Brueggeman of Envirosphere Company[a] edited the report and he was assisted in preparing each section of the report by R. Grotefendt[b] and D. Chapman[c] except Section 3.0 entitled Sea Ice Monitoring Methods. R. Grotefendt was responsible for data management and D. Chapman managed the data analysis. Section 3.0 was prepared by B. Webster[d] except for Subsection 3.3 entitled Feasibility Analysis of Monitoring Systems which he and J. Brueggeman prepared together. Other personnel who assisted in the project were J. Groves who provided data on pack ice location, composition, and polynyas in the Bering Sea; D. Ljungblad who provided the 1986 data base of bowhead distribution; and G. Green and L. Balzer who coordinated the preparation of the report.

We are grateful for the support provided by W. Benjey, C. Cowles, and their staff of the U.S. Minerals Management Service.

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Abstract--The purpose of this study was to determine the statistical association between bowhead whales and pack ice in the Bering Sea and to evaluate the feasibility of monitoring this relationship from remote sensing observation systems. The study was done entirely from information in existing data bases and literature. Three data bases containing 133 groups of 239 bowhead whales and 12,561 nautical miles (nmi) of survey effort in the Bering Sea were used to describe the bowhead whale-pack ice association. The 1979 data base contained 83 groups of 141 bowheads encountered along 6,496 nmi of trackline distributed in a northern zone, central zone, and southern zone (marginal ice front) of the pack ice. The 1983 data base featured 32 groups of 60 bowheads along 4,056 nmi of trackline in the marginal ice front. Lastly, the 1986 data base had 18 groups of 38 bowheads along 2,009 nmi of trackline in the central zone and marginal ice front. These three data bases provided coverage of the pack ice from January through April which largely corresponds to the period bowheads winter in the Bering Sea.

The results show that bowheads were widely distributed in the Bering Sea between January and April. Bowheads were recorded in the marginal ice front during all three surveys. Their distribution was patchy, and relatively high numbers of whales occurred in the St. Matthew Island vicinity. The orientation of the whales relative to the island suggested that the island vicinity was an important concentration area for bowheads and that they appeared to passively move with the advance of the pack ice between St. Lawrence and St. Matthew islands. Whales appeared to be associated with the recurring polynya at St. Matthew Island irrespective of the southern extent of the front beyond the island.

Bowheads were also distributed south and west of St. Lawrence Island but more uniformly than in the front. These whales were near the recurring polynyas of St. Lawrence Island and the northern Anadryskiy Gulf (Gulf of Anadyr). Few whales were encountered away from these locations in the central zone. In all areas, bowheads were primarily encountered in small groups (≤ 2) moving in no specific direction.

Bowheads encountered in these locations in the pack ice were associated with a wide variety of ice conditions. Bowheads occurred in 10 of the 11 ice concentration categories used to characterize the pack ice. Numbers were disproportionately greater in the higher ice concentrations but this may have been a function of the whales being easier to detect where less open water was available. In conjunction with the variety of ice concentrations associated with the whales, the areas used in the pack ice had persistent open water available over time. Their association with areas featuring persistent open water and a variety of ice concentrations correspond to the pack ice characteristics in the vicinities of the three polynyas and the ice front. The pack ice in these areas is very broken because the ice movements around the islands and the marginal ice front are very dynamic.

Regression equations were formulated for. predicting the presence or absence of bowheads in the pack ice and the density of bowheads given that they are present. The equations were suggestive of a predictive relationship using various forms of ice concentration and persistence of open water but inconclusive because of small numbers of whales observed.

While the capacity to mathematically predict a bowhead-sea ice association was inconclusive, there were several important conclusions from this study. The St. Matthew Island vicinity appears to be an important wintering area for bowhead whales. The area south and west of St. Lawrence Island including the northern Gulf of Anadyr also appears to be an important bowhead whale wintering area. In addition, the pack ice between longitudes 171°W and 175°W from St. Lawrence Island to St. Matthew Island may be an important movement corridor for bowheads. While bowheads occurred elsewhere in the pack ice, these locations contained relatively large numbers of bowheads wintering in the pack ice of the Bering Sea.

Remote sensing and surface-based observation systems suitable for monitoring the association between bowhead whales and sea ice were described and their operational costs determined. Remote sensing systems examined included both satellites and airborne/surface radar. Surface-based observation systems included “point” observations from moored or drifting buoys or visual observations from aircraft.

The effectiveness of each technique in providing ice information relevant to monitoring the winter presence of bowhead whales in the Bering Sea was evaluated in terms of their capabilities in detecting the morphology of the pack ice and the timeliness and method of data relay to government officials (Minerals Management Service) for monitoring purposes. Fulfillment of the system requirements for an effective ice monitoring system can be met by a combination of satellite and airborne radar surveillance systems. Only Side Looking Airborne Radar has the demonstrated capability as a stand-alone effective ice monitoring system. Site-based radar has limited range capabilities and, thus, fails to meet the lead-time criteria for “ice alert” status. Ship-based marine search radar has potential application but must be used in combination with other systems which are capable of broadly describing the ice characteristics.

The use of moored buoys which sense the presence of sea ice either through acoustical means or through physical contact is feasible. Acoustical detection of sea ice for operational purposes is a future capability which will materialize only after research and field development. Specially designed satellite telemetering moored buoys which are monitored from the Service Argos, will, hypothetically, indicate the presence of ice when the buoys are submerged beneath the ice and cease their signal transmission.

The most expensive approach is the aircraft equipped with Synthetic Aperture Radar (SAR) or Side Looking Radar (SLR). Both of these systems provide the necessary information on sea ice characteristics with all weather, day and night capability which can be delivered to the operator and MMS personnel within three hours after observation. Pulse compression radar, which is an upgrade to standard marine search radar, is far less costly than microwave radar to operate but it does not provide the range of ice information needed to make operational decisions.

Satellite imagery and point observations from buoys have obvious shortcomings in providing the kind of ice information desired but are useful components of an ice observation program employing airborne or satellite microwave radar. The costs involved with receiving and analyzing the NOAA, Landsat and, presumably, the Geosat satellite information for ice conditions are small in comparison with operating an aerial surveillance program employing microwave radar. Although the costs associated with monitoring the position or ice contact events of either drifting or tethered buoys are relatively low, the expense of development, deployment, and retrieval can be significant.

In the future, SAR satellites will likely satisfy some of the requirements for all-weather ice information if near-real-time data can be generated and easily accessed at the Alaska SAR Facility. The costs of accessing the satellite SAR ice images presently cannot be determined but will ultimately depend upon NOAA's plans for servicing the commercial sector. Sea ice information derived from passive microwave sensors on the future military satellites [and as a complement sensor on some of the satellites carrying SAR) will most likely be available from the NOAA/Navy Joint Ice Center at no cost to the user except for leasing the facsimile equipment and data communication link.

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RATIONALE AND OBJECTIVES

1.0 RATIONALE AND OBJECTIVES

The purpose of this study was to statistically analyze the relationship between bowhead whales and sea ice in the Bering sea and to examine the application of remote sensing systems for detecting ice conditions associated with bowhead whales. The western arctic bowhead whale is a federally listed endangered species whose population winters in the Bering Sea pack ice. Their wintering area coincides with the Navarin Basin, St. Matthew - Hall Basin, and St. George Basin petroleum lease areas. Since petroleum exploration and production in these areas could affect the bowhead population, the Minerals Management Service sponsored this study to determine the feasibility of managing petroleum operations around bowhead whale wintering areas by remote sensing systems.

The hypothesis for the study was that bowheads are associated with specific ice conditions that could be recognized from remote sensing systems. Studies by Brueggeman (1982) suggested that bowheads may prefer areas in the pack ice characterized by particular ratios of ice to open water. If the association between bowhead whales and ice conditions could be mathematically expressed in an equation, bowhead density could be predicted for a particular set of ice conditions. This predictive capability could be used in conjunction with a remote sensing system such as a satellite to identify ice conditions associated with bowheads. This approach would be cost effective because the pack ice could be more thoroughly and frequently monitored than is generally possible through expensive field programs. The remote sensing system would have to be dependable, capable of providing daily images, and not too expensive for a user to access. The resulting system would provide MMS with a powerful tool for managing petroleum operations in the vicinity of bowhead whales on an almost real time basis.

The objectives of this study were:

1. Define the relationship of the winter distribution of bowhead whales in the Bering Sea relative to the position and morphology of the sea ice edge by:

a. Improving current knowledge of the winter distribution of bowhead whales in the Bering Sea by compiling and analyzing available information, and

b. Relating the Bering Sea ice cover and ice margin to the winter distribution and abundance of bowhead whales, especially within the Navarin Basin.

2. Define the most feasible means of monitoring sea ice cover relative to probable bowhead whale presence by:

a. Comparing various sea ice cover observation techniques, and

b. Recommending the most feasible method of monitoring the sea ice margin.

These objectives are addressed in Sections 2.0 and 3.0 of the report. Section 4.0 contains the recommendations of the study.

2.0
WINTER DISTRIBUTION OF BOWHEAD WHALES

2.0 WINTER DISTRIBUTION OF BOWHEAD WHALES

2.1 INTRODUCTION

The geographic range of the western arctic bowhead whale population extends from the Bering Sea to the Beaufort Sea in Canada (Braham et al. 1984). The population inhabits the Bering Sea during winter and spring when sea ice precludes its use of the summer/fall feeding grounds in the Beaufort Sea (Brueggeman 1982, Richardson et al. 1985, Ljungblad et al. 1986). Migrations between the Bering and Beaufort seas follow a recurring lead on the U.S. side of the Chukchi Sea during spring, whereas the U.S.S.R. side is followed during the fall (Ljungblad et al. 1986, Miller et al. 1986). The size of the western arctic bowhead whale population has declined from an estimated 20,000 animals (Breiwick et al. 1984) prior to commercial exploitation to approximately 4,000 animals (Krogman et al. 1986).

Bowhead whales occupy the Bering Sea from approximately November through April (Brueggeman 1982, Brueggeman et al. 1983). The western arctic population historically occurred in the Bering Sea yearlong (Bockstoce and Botkin 1983). During the initial period of commercial exploitation (1849-1858) bowheads were taken from April through October in the Bering Sea (Bockstoce and Botkin 1983). The catch of bowheads during these months suggests that the area was a feeding ground. As the population was reduced, whalers moved farther north to maintain their catch levels. Bowheads appear to have been eliminated from this summer feeding area, since there have been no recent sightings in the Bering Sea during the ice free period (Brueggeman et al. 1983). This historic information indicates that the original range of the western arctic bowhead whale population in the Bering Sea was above 54″N from the coast of Asia to about 173°W (Bockstoce and Botkin 1983). Scammon (1874) reported that bowhead whales were seldom seen in the Bering Sea south of 55°N latitude.

Recent studies (Brueggeman 1982, Brueggeman et al. 1985) show that bowheads are widespread in the pack ice of the Bering Sea during winter and spring. These studies found relatively large concentrations of bowheads near St. Matthew Island, St. Lawrence Island, and the northern coast of the Gulf of Anadyr. Hanna (1920) reported that bowhead bones were exceedingly abundant on all beaches of St. Matthew Island during a 1916 field survey. Soviet scientists reported that bowheads winter off the northern coast of Anadyr where they have been traditionally hunted by Siberian Eskimos (Bogoslovskaya and Votrogov 1981, Bogoslovskaya et al. 1982, Fedoseev 1982). Because bowheads primarily migrate through the Strait of Anadyr during the spring and fall, they have been observed near St. Lawrence Island throughout the fall-winter-spring period (Kenyon 1972, 1960, Braham et al. 1984). Whales have also been reported to winter in the southern margin of the pack ice, particularly near Cape Navarin (Scammon 1874, Aldrich 1889, Cook 1926, Zenkovich 1954). More recent surveys have reported small numbers of bowheads in the pack ice from approximately Cape Navarin to southeast of St. Matthew Island (Brueggeman 1982, Brueggeman et al. 1983, Leatherwood et al. 1983). Whales have not been recently reported south of the pack ice in the Bering Sea (Ljungblad et al. 1986).

The western arctic bowhead whale population appears to remain in the Bering Sea pack ice during the winter-spring. Bowheads found in the vicinity of St. Matthew Island, St. Lawrence Island, and the northern coast of the Gulf of Anadyr are associated with polynyas or recurring areas of open water in the pack ice (Brueggeman 1982, Bogoslovskaya et al. 1982, Brueggeman et al. 1983). Bowheads, however, also occur elsewhere in areas of the pack ice represented by a variety of ice conditions and geographic locations. It is currently unclear if there is a consistent and predictable association between characteristics of the sea ice and the distribution pattern of bowhead whales.

The purpose of this report was to assemble one available data base of bowhead whale observations in the Bering Sea and correlate the observed distribution to sea ice conditions. The objectives were to:

- Identify data bases suitable for analysis;
- Standardize the data bases so that the findings could be compared and merged into a comprehensive data set; and
- Correlate ice characteristics with bowhead distribution so that sea ice could be used to predict bowhead density.

The results of the analysis were linked in this report with satellite observation systems to predict important areas of bowhead use. These areas will be identified from maps for the purpose of managing oil exploration and production activities on the outer continental shelf of the Bering Sea to avoid adversely affecting the western arctic bowhead whale population.

2.2 METHODS

2.2.1 Description and Compatibility of Data Bases

The literature was extensively searched to identify sources of data suitable for analysis. Historic and current, published and unpublished literature was reviewed. Literature relevant to describing the association between bowhead whales and pack ice in the Bering Sea was summarized and is provided in Appendix A. The literature was summarized according to a structured format for documenting the applicability of the information for analysis. While there were numerous references in the literature to bowhead use of the Bering Sea pack ice, there were only three reported studies with data bases suitable for quantitative analysis. These data bases are the sources of information we used to describe the association of bowhead whales with pack ice in the Bering Sea.

The data bases used for the analysis are the results of surveys conducted in the Bering Sea pack ice during 1979, 1983, and 1986. The surveys occurred at various times between January and April when bowheads inhabit the Bering Sea. Each data base is described below.

1979 Data Base

The 1979 data base was derived from aerial surveys conducted by Brueggeman (1982) in the Bering Sea pack ice from March 3 to April 15, 1979. Eighty-three groups of bowhead whales comprising 141 animals were recorded during 6,496 nmi of survey. The survey design and data collection procedures are fully described below.

The study area was stratified into three survey zones (Figure 2-la, b). Fifteen sampling units, each approximate'y 30 nmi long by 32 nmi wide, were distributed systematically within these zones. The southern zone or marginal ice front contained seven sampling units, the northern zone five units, and the central zone three units. The southern and northern zone locations were selected because bowheads have been historically reported by whalers to winter in these areas. The central zone was selected because it lies south of the Strait of Anadyr where whales pass through in the spring and fall. There were no surveys south of the pack ice in the open ocean.

Aerial surveys were conducted from two Sikorsky H-52-A helicopters based on the U.S. Coast Guard icebreaker Polar Sea. The helicopters flew parallel at 150 to 230 m altitudes and 65 to 80 kt speeds along paired transect lines. Eight paired strip transect lines, approximately 30 nmi long and 1 nmi apart were aligned with longitudinal lines (north-south) and spaced every 3 nmi in each sampling unit. A directional radio-navigational system (TACAN) was used between helicopters and the ship to guide the aircraft along the transects. Single helicopter surveys were flown in sampling units 11 to 15 because one helicopter was not operational.

Two observers, one positioned in the copilot seat and one in the right-aft section of each helicopter, provided data on marine mammals and environmental conditions to a dedicated data recorder. Data collected on bowhead whales included number, group size, behavior, calves, time, and location. Environmental conditions including visibility (Appendix A) and glare (percentage of viewing area) were

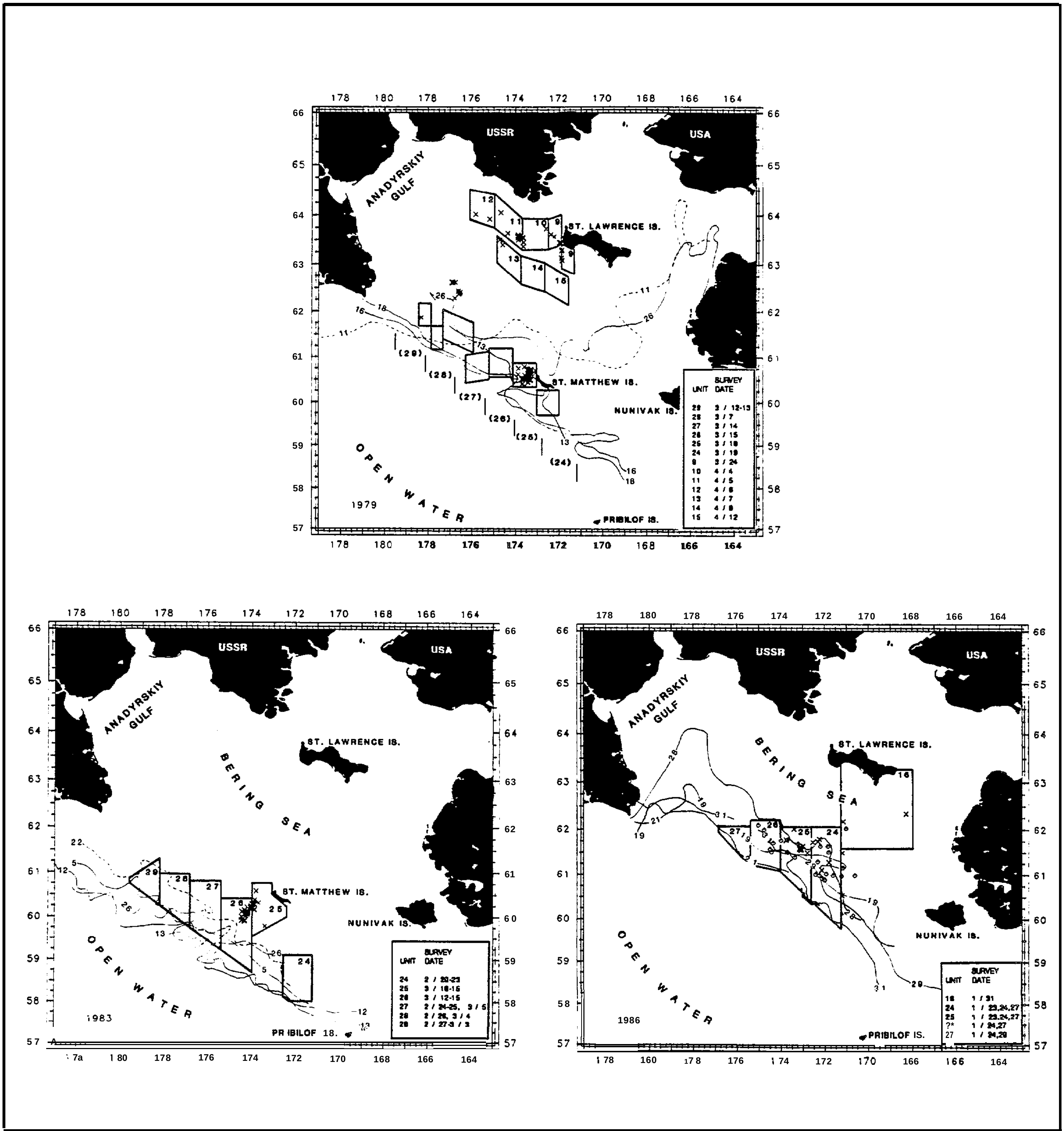

Figure 2-1 a . Bowhead whale distribution (x = whale location; o = whale vocalization detected by sonobuoy) in the Bering Sea pack ice -1979, 1983, 1986. Ice edges are illustrated for selected dates (number) in March (—) and April (---) 1979, February (---) and March (—) 1983, and January (—) 1986.

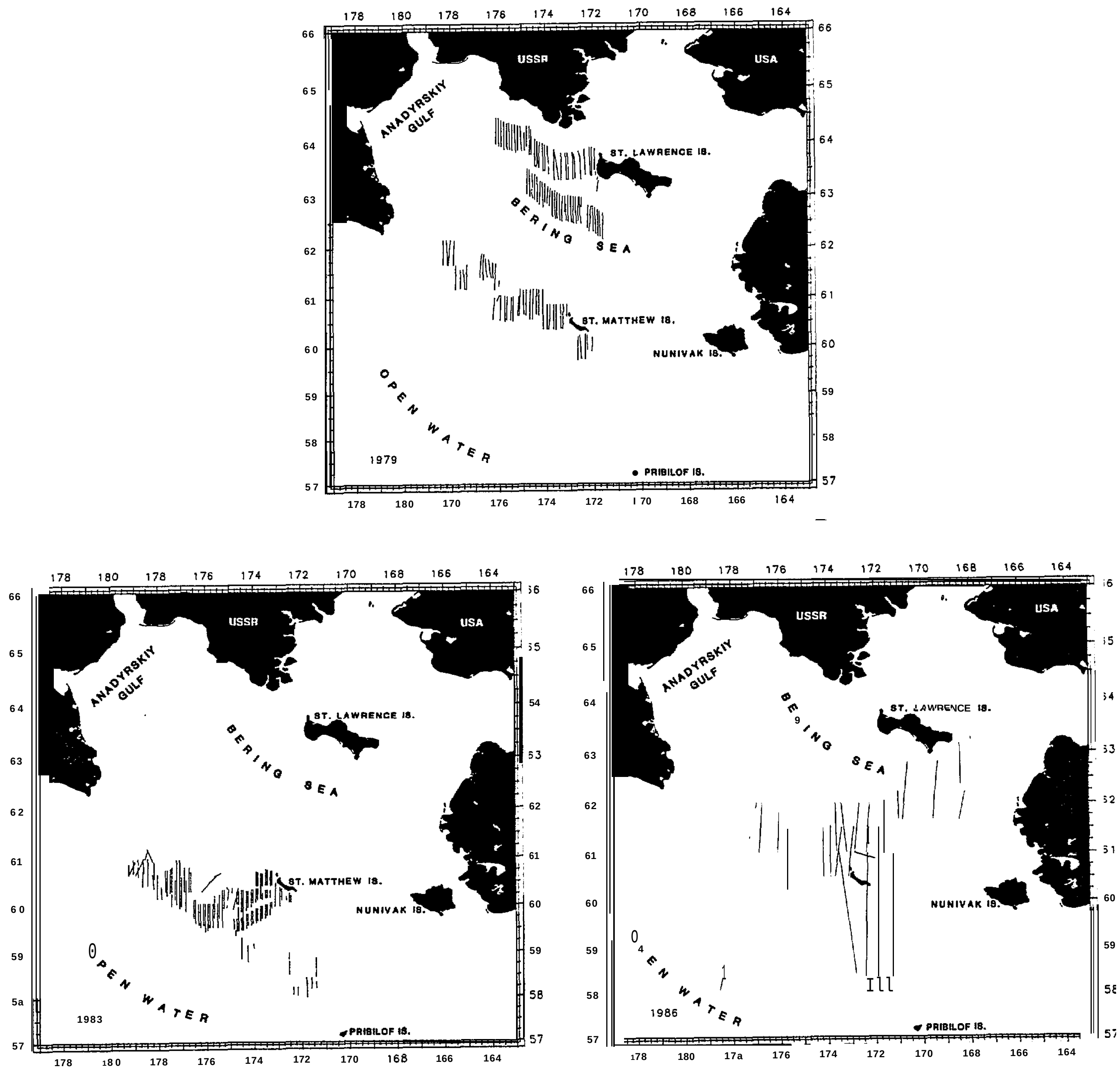

Figure 2-lb . Survey effort distribution in the Bering Sea - 1979, 1983, 1986.

evaluated by each observer at the start of each transect line and whenever conditions changed. Ice concentration (percentage) and floe size (percentage) were visually evaluated every 3 minutes along each transect line by the observer in the copilot seat (Appendix A). Ice conditions were evaluated by the same observer for the area surveyed by both aircraft in order to maintain consistency in the data. Ice nomenclature followed that of the World Meteorological Organization (1970).

Limited vessel surveys were conducted along the transect lines when aerial surveys were terminated because wind speed exceeded 25 kt, ceiling height was below 91 m, visibility was less than 2 nmi, or both helicopters were not operational. Too few data were collected during vessel surveys for analysis.

1983 Data Base

The 1983 data base was derived from aerial and vessel surveys conducted by Brueggeman et al. (1983) in the Bering Sea pack ice from February 19 to March 18, 1983. Thirty-two groups comprising 60 bowheads were recorded during 4,056 nmi of surveys. The survey design and data collection procedures were similar to those followed in 1979 and they are described below.

Surveys were limited to the marginal ice front between longitudes 171°12'W and the U.S.-U.S.S.R. convention line (Figure 2-la, b). Six sampling units, approximately 36 nmi wide and 30 to 60 nmi long, were distributed across the front. Surveys were conducted along seven-paired transect lines established in each sampling unit. The paired transect lines were spaced every 4 nmi and were aligned along the longitude lines. Individual transect lines comprising each pair were separated by 2 nmi and extended 30 to 60 nmi into the pack ice from the interface of the marginal ice front with the open ocean. Surveys were not conducted in the open ocean because of high seas.

Aerial surveys were conducted from two Sikorsky H-52-A helicopters based on the U.S. Coast Guard icebreaker Polar Sea. The helicopters flew transect lines parallel to each other or singly at altitudes of 150 to 230 m and speeds of65 to 80 kt. The orientation of the observers in the aircraft and the data collection procedures were identical to those described in 1979 except for several modifications. The navigation was determined from a Loran-C system on each helicopter which is more precise than the TACAN system used in 1973. Ice thickness in addition to ice concentration and floe size was visually evaluated every 3 nmi (versus 3 minutes) along the transect lines by the observer occupying the copilot seat in each helicopter. Ice characteristics were evaluated by the same observers for every survey in order to maintain data consistency.

Single helicopter surveys were conducted when one helicopter was out of operation. The U.S. Coast Guard restricted the range of single helicopter surveys to 8 nmi from the vessel. In order to maximize the use of a single helicopter, the ship traveled a predetermined course that bisected the survey transect lines while the helicopter flew 8 nmi both north and south of the ship. Single helicopter surveys were flown in units 25 and 26.

Vessel surveys were conducted along the transect lines in place of aerial surveys when wind speed exceeded 25 kt, ceiling height was below 91 m, visibility was less than 2 nmi or both helicopters were not in operation. During vessel surveys, observers were stationed in the loft conning tower, 34 m above the surface of the water. Two observers, one on the port and one on the starboard sides, recorded bowhead whales occurring in a 90° arc centered on the bow of the vessel. The position of an animal from the vessel was determined simultaneously by obtaining a radial angle with a sighting board and a vertical angle with a clinometer. Data recorded on ice, environmental conditions, and animal sightings followed the same procedures described above for the helicopters. Vessel surveys were also conducted during single helicopter surveys when observers were available.

1986 Data Base

The 1986 data base was derived from aerial surveys conducted by Ljungblad et al. (1986) in the pack ice and open water of the Bering Sea from January 23 through January 31, 1986. Eighteen groups comprising 38 bowheads were recorded during 2,009 nmi of survey in the pack ice (Figure 2-la, b). Over half of the total effort was spent flying over open water from Adak to the pack ice, but poor weather precluded suitable observation conditions. The survey pattern was designed to complement and expand upon that used by Brueggeman (1982) and Brueggeman et al. (1983).

Fourteen sampling units, each one latitude degree by three longitude degrees, were systematically distributed between latitude 58°N and 63°N and longitude 171°W to the U.S.-U.S.S.R. convention line. Approximately nine units were in open water and five units were in the pack ice, primarily the marginal ice front. Each unit was divided into equidistantly spaced transect lines oriented in a north-south direction. Transect lines were randomly selected for survey and all whales occurring in a 0.50 nmi strip on each side of the transect line were counted.

Aerial surveys were conducted from a P-3 Orion aircraft. Surveys were flown at 305 m altitude or lower depending on ceiling height and at 170 to 210 kt speeds along the transect lines. Observers, positioned behind the pilot and copilot, relayed observations to a data recorder seated in the aft section of the aircraft. Data were logged into an on-board computer that automatically recorded the speed, altitude, and position of the aircraft in real time. These data were recorded at 10 minute intervals along with information provided by the observers on visibility, sea state (Beaufort wind scale), ice conditions, and glare. Data recorded for each whale sighting were number, group size, direction of travel, behavior, and vertical angle of animal to aircraft for determining perpendicular distance from transect line. This information was linked with the location and environmental condition data to provide a comprehensive sighting record for each animal.

Sonobuoys were also deployed from the aircraft along the transect lines to monitor bowhead whale sounds. Sonobuoys were used to complement the observations by documenting the presence or absence of vocalizing whales in the study area.

Compatibility of Data Bases

The 1979 and 1983 data bases were very compatible (Table 2-l). The similarities between the 1979 and 1983 data bases included identical survey platforms, flight and vessel speeds, and aircraft altitudes on projects managed by the same person. Survey periods largely overlapped and study areas included the marginal ice front from the St. Matthew Island vicinity to the U.S.-U.S.S.R. convention line. The 1979 survey also included the pack ice south and west of St. Lawrence Island. Environmental conditions and sighting data were measured the same way while ice conditions were measured slightly different during the two years. Ice thickness was measured only in 1983 and ice concentration was estimated in oktas (1/8) in 1979 and deciles (1/10) in 1983. All ice concentration estimates were converted to percentages. Lastly, a line transect survey procedure was followed in 1983 and a strip transect survey procedure in 1979.

The 1986 surveys were different from the 1979 and 1983 surveys in that a much larger aircraft was flown at a higher speed and altitude. In addition, the surveys were conducted earlier than the other two but in the marginal ice front from the St. Matthew Island vicinity to the U.S.-U.S.S.R. convention line. Surveys were also conducted in the open water which was not attempted in 1979 or 1983. Data on environmental and sighting conditions were collected in a manner similar to the other survey periods. Ice concentration was estimated in deciles while ice thickness was not determined in 1986. Lastly, a strip transect survey procedure was used in 1986.

While differences exist among the three data bases, they are sufficiently compatible to evaluate the association of bowhead whales to sea ice. Ice conditions (floe size and ice concentration), effort,

TABLE 2-1

SURVEY CHARACTERISTICS OF THE 1979, 1983, and 1986 BOWHEAD WHALE DATABASES FOR THE BERING SEA

Survey Characteristics	Data Base 1979	1983	1986
o Survey Period			
January		-	X
February - March		X	-
March - Apri 1	X		-
o Survey Platform			
- Type			
Helicopter (Sikorsky H-52-A)	X	X	-
Vessel (Polar Sea Icebreaker)	X	X	-
Airplane (P-3 Orion)			X
- Survey Speed			
65-80 kt	X	X	-
170-210 kt	-	-	X
6-8 kt (vessel)	X	X	-
- Survey Altitude			
150 - 230 m	X	X	-
305 m			X
o Data Collection Procedures			
- Strip width			
Bound (1.00 nmi)	X	-	X
Unbound		X	-
- Environmental conditions			
Visibility	X	X	X
Gl a re	X	X	X
- Ice conditions			
Ice concentration	X	X	X
Floe size	X	X	X
Ice thickness		X	-
- Sighting data			
Number	X	X	X
Group size	X	X	X
Direction of movement	X	X	X
Behavior	X	X	X
o Location			
Open ocean	-	-	X
Marginal ice front	X	X	X
Deep pack ice	X		-

and environmental conditions were estimated for all three survey periods by using similar procedures during a time frame when bowheads were present in the Bering Sea pack ice. These variables are necessary for describing the bowhead whale-sea ice association.

2.2.2 Data Analysis

Before initiating data analysis, sea ice measurements were made compatible among the data bases. Ice conditions in the 1983 data base were estimated from both a vessel and helicopters. A paired t-test of ice concentration at 68 matched locations showed the percent cover estimates were significantly different ($p<0.05$) between the vessel and helicopter. Vessel observers consistently overestimated ice concentration for areas exceeding 50 percent cover and underestimated it in areas at or below this value when compared to helicopter observer estimates. Ice concentration values estimated from the vessel were adjusted to match those from the helicopter, which are believed to be the most accurate values. The helicopter provided a vertical view of the pack ice to observers compared to an oblique view from the vessel. Furthermore, most of the total area surveyed (68 percent) was by helicopter and helicopter observers counted most of the whales (66 percent) .

Two procedures were used to adjust the vessel estimates of ice concentration. The first procedure was to use a regression equation to adjust ice concentration values exceeding 50 percent ice coverage. The regression equation was:

$$AIC = 5.63 + 0.247 (VIC)$$

where:

AIC = Adjusted Ice Concentration (percent)
VIC = Vessel Estimated Ice Concentration (>50 percent)

The regression was significant ($p = 0.242$), but the r value (0.16696) was low. This procedure was, however, the best approach for adjusting the vessel estimates for the higher ice concentrations (D. Chapman, pers. comm.).

A different procedure was followed to adjust the 50 percent or less ice concentration values estimated from the vessel. There were too few matched locations for ice categories within the 0 to 50 percent cover range to develop a regression equation. As an alternative, a linear relationship was derived by determining the average differences in the ice concentration between the vessel and helicopter estimates for the category with the highest number of matched location observations (Figure 2-2). The 40 to 50 percent ice concentration category had 17 of the total 18 matched location observations with an average difference of 31.2 percent. A line was connected between this value and the origin which represented zero ice; both vessel and helicopter observers would accurately estimate areas having no ice. One matched location for an intermediate ice concentration (20 percent) fell near the line which supported the assumed linear relationship. The ice concentration estimates for the vessel were adjusted in the 0 to 50 percent categories from the following equation:

$$AIC = 0.624\,(VIC) + (VIC)$$

where:

VIC = Vessel Estimated Ice Concentration (≤ 50 percent).

Another inconsistency in the data bases that required adjustment was the unit of measurement for describing ice concentration. Ice concentration was estimated in oktas (1/8) in 1979 and deciles (1/10) in 1983 and 1986. These values were converted to percentages and proportioned into the following categories for describing sea ice concentration in the project area during 1979, 1983, and 1986:

0 - 5 percent	45 - 55 percent
5 - 15 percent	55 - 65 percent
15 - 25 percent	65 - 75 percent
25 - 35 percent	75 - 85 percent
35 - 45 percent	85 - 95 percent
	95 - 100 percent

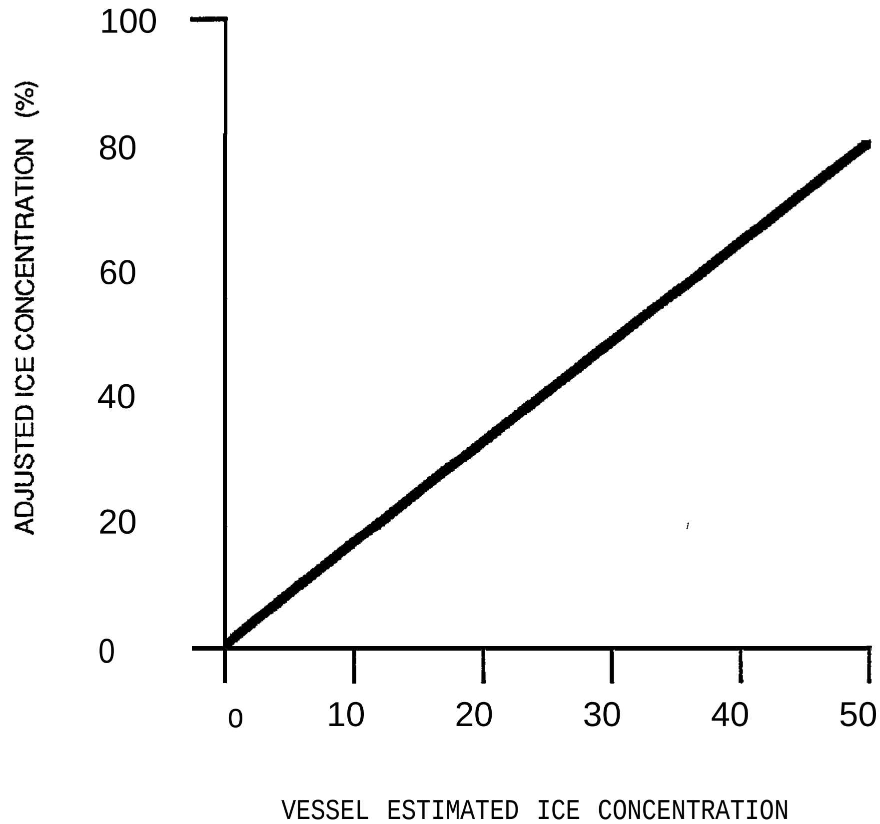

Figure 2-2 Actual and adjusted ice concentration estimated by vessel observers during 1983 survey

This categorization was chosen because it provided higher resolution in the extreme categories that are most accurately estimated in the field and broader resolution for the intermediate categories that are more difficult for observers to visually distinguish. Other ice condition features including floe size and ice thickness were not adjusted for the data bases. Floe size estimates were sufficiently accurate for analysis since the size categories were much broader and, therefore, more accurately estimated than ice concentration. Ice thickness was only recorded in 1983. Ice nomenclature followed that of the World Meteorological Organization (1970).

The analysis of the association of bowhead whales with sea ice centered on the availability of area in which an observer could see a whale in the pack ice during a survey. The only area a whale could be seen was in open water or grease ice. Grease ice is sufficiently thin to permit an observer to see a whale. Whales normally could not be seen through first year ice. Therefore, ice concentration was adjusted for grease ice by treating it as water. Whale association with the pack ice was correlated with the availability of open water including grease ice within the eleven concentration categories. Since ice concentration and floe size were not independent ($p<0.001$) variables (i.e., floe size increased as ice concentration increased) and ice concentration best reflected the availability of surveyable area, it was the primary characteristic used to explain bowhead association with ice.

The analysis of this relationship was conducted in two broad steps. The first step was an analysis of the presence or absence of bowhead whales in the various ice concentrations. The purpose of this analysis was to predict presence or absence of whales for a given ice concentration. The second step was an analysis of this relationship for those areas in which whales were present. The purpose of this analysis was to predict number of bowhead groups in a specific ice concentration provided whales were present. The analyses were done for each survey year and all years combined.

The presence or absence analysis step was conducted in two phases. The first phase was to incorporate the entire data base into the analysis by using both the trackline and whale locations. Tracklines were divided into 3,403 segments that corresponded to changes in ice concentrations. The distance surveyed in each segment was linked to a specific ice concentration and the presence or absence of a whale. There were 3,291 trackline segments without whales and 112 segments with whales. A second phase of the analysis was to evaluate the presence or absence of whales for the variables ice concentration and persistence of open water. Inclusion of this latter variable assumed that if whales were associated with the availability of open water in a given ice concentration then the persistence of that water may be important in predicting presence or absence.

Persistence of open water was evaluated for 126 cells (5 min. latitude by 10 min. longitude) from NOAA satellite imagery. Each cell was classified according to six categories: 1) open water surrounded by ice, 2) mixed ice and water, 3) closed or frozen, 4) open ocean, 5) cloud covered, or 6) no imagery. The cells were classified by superimposing a transparency of the cell locations onto a satellite image photo and determining the persistence category for each cell, Image distortion was compensated for by manually adjusting the image to fit a rectified map developed for the respective image. One hundred and sixty of 265 total photos examined were sufficiently cloud free for analysis. This included 70 days of coverage between January and April 1979, 65 days between January and April 1983, and 25 days for January 1986 (Table 2-2). Photo coverage was generally complete for each of these months, which overlapped the survey periods and time bowheads inhabit the Bering Sea; time constraints limited the 1986 analysis to the January survey period. While temporal coverage was good, spatial coverage was variable as described by the categorical percentages of cells visible per photo (Table 2-3). In general, however, the persistence values were derived from a large base of imagery somewhat evenly distributed across the months and the study area.

TABLE 2-2

NUMBER OF DAYS OF USABLE NOAA SATELLITE IMAGERY FOR DETERMINING PERSISTENCE OF OPEN WATER AT 126 CELLS IN THE STUDY AREA DURING 1979, 1983, AND 1986

Month	1979	1983	1986
January	9	19	25
February	20	20	0
March	21	22	0
April	20	12	0
Total	70	65	25

TABLE 2-3

NUMBER OF DAYS OF USABLE NOAA SATELLITE IMAGERY WHERE A PERCENTAGE OF THE TOTAL 126 CELLS SAMPLED WAS VISIBLE FOR DETERMINING THE PERSISTENCE OF WATER DURING 1979, 1983, AND 1986

	Number of Days Per Category				
Year	0-25 percent	25-50 percent	50-75 percent	75-100 percent	Total Number
1979	24	4	12	30	70
1983	26	14	4	21	65
1986	8	1	4	12	25

The statistical procedures used to analyze the presence or absence relationship to sea ice were the chi-square and the multiple regression, Stepwise multiple regression was used to predict presence or absence of bowheads for the dependent variables of ice concentration and persistence of water.

Given whales were present, the second step in the analysis was to predict number of bowhead groups per nautical mile of water in the various ice concentration categories. Chi-square and stepwise multiple regression were used to test this relationship. The dependent variables used in the regression were ice concentration and persistence.

2.3 RESULTS

A total of 133 groups representing 239 bowhead whales were observed in the Bering Sea pack ice during 12,561 nmi of survey in 1979, 1983, and 1986 (Table 2-4). Approximately 60 percent of the whales were recorded in 1979, 25 percent in 1983, and 15 percent in 1986. Correspondingly, survey effort was highest in 1979 and lowest in 1986. Weather conditions during these survey periods were quite variable but they seldom affected the observability of the whales from the survey platforms. The influence of wind speed on the water was greatly reduced by the pack ice. Fog and blowing snow hindered the observability of bowheads, so surveys were not conducted during these conditions.

2.3.1 Distribution and Group Size

Bowheads occurred in all three zones of the pack ice (Figure 2-la). Numbers were highest in the southern zone or marginal ice front, lowest in the central zone, and intermediate in the northern zone. The northern zone was surveyed in 1979 when whales were widespread in each of the four survey units. The central zone was surveyed in 1979 and 1986 when whales were recorded both southeast and southwest of St. Lawrence Island. The southern zone or marginal ice front was surveyed during all three years. Whales were widely distributed in the

TABLE 2-4

EFFORT AND NUMBER OF BOWHEAD WHALES OBSERVED IN THE STUDY AREA, 1979, 1983, AND 1986

Zone	Sampling Unit[a]	1979 Survey distance (nm)	1979 Number	1979 Groups	1983 Survey distance (nm)	1983 Number	1983 Groups	1986 Survey distance (nm)	1986 Number	1986 Groups	TOTAL Survey distance (nm)	TOTAL Number	TOTAL Groups
Northern	9	696.6	30	12	0.0	--[b]	--	0.0	--	--	696.6	30	12
	10	548.1	7	7	0.0	--	--	0.0	--	--	548.1	7	7
	11	341.5	11	7	0.0	--	--	0.0	--	--	341.5	11	7
	12	348.0	3	2	0.0	--	--	0.0	--	--	348.0	3	2
Subtotal		1,934.2	51	28	0.0	--	--	0.0	--	--	1,934.2	51	28
Central	13	316.8	3	2	0.0	--	--	0.0	--	--	316.8	3	2
	14	369.2	0	0	0.0	--	--	0.0	--	--	369.2	0	0
	15	332.5	0	0	0.0	--	--	0.0	--	--	332.5	0	0
	16	0.0	--	--	0.0	--	--	587.9	3	2	587.9	3	2
Subtotal		1,018.5	3	2	0.0	--	--	587.9	3	2	1,606.4	6	4
Southern or Marginal Ice Front	24	289.0	0	0	213.6	0	0	672.6	14	7	1,175.2	14	7
	25	924.7	86	52	831.9	20	14	620.4	21	9	2,377.0	127	75
	26	809.7	0	0	1,027.9	40	18	111.2	0	0	1,948.8	40	18
	27	807.7	0	0	687.9	0	0	16.7	0	0	1,512.3	0	0
	28	712.2	1[c]	1	886.2	0	0	0.0	--	--	[illegible]	1	1
	29	0.0	--	--	408.9	0	0	0.0	--	--	-	0	0
Subtotal		3,543.3	87	53	4,056.4	60	32	1,420.9	35	16	9,020.6	182	101
TOTAL		6,496.0	141	83	4,056.4	60	32	2,008.8	38	18	12,561.2	239	133

a/ Zones and the associated sampling units corresponded to the morphology of the pack ice irrespective of geography.

b/ Dash signifies the unit was not surveyed.

c/ An additional ten groups representing 18 bowheads were recorded north of unit 28.

5081a

front but relatively high numbers of whales were concentrated near St. Matthew Island in Units 24, 25, and 26. The distribution was extremely clustered in 1979 at longitude 173°W, and in 1983 at longitudes 173°W and 174°W (Figure 2-3). The'whales were more scattered in 1986 between longitudes 171-173°W when surveys were conducted in Janury and the ice edge was north of St. Matthew Island. These results show that while bowheads were widespread in the pack ice, they annually concentrated in the marginal ice front from longitudes 172°W through 175°W.

The distance of whales from the ice edge into the pack ice was variable (Figure 2-4). Distance equalled the difference between the location of a group of whales and the closest ice edge. Measurements were made only when an ice edge could be delineated for the same day a whale was sighted. It would have been inaccurate to use ice edge positions and whale locations for different days because of the highly dynamic movements of the pack ice. Ice edge locations were delineated from NOAA satellite imagery that was transferred to a base map and geographically rectified. The ice edge was defined as the southernmost boundary of the pack ice. The results show that bowheads occurred close to the ice edge but also deep into the pack ice. Determination of the ice edge boundary was limited, however, by the resolution of the NOAA satellite imagery (1.0 km). Consequently, bowhead distribution in the pack ice did not appear to be entirely associated with ice edge location.

Whales encountered in the pack ice were usually in small groups during 1979, 1983, and 1986 (Figure 2-5). Over 60 percent of the whales recorded were singles. Group sizes did not exceed 6 animals except in 1983 when 1 group of 12 animals was recorded. A group was defined as an aggregate of animals within three to five body lengths of each other. These results contrast to much larger group sizes reported for whales feeding in the Beaufort Sea (B. Wursig, pers. comm.). The group sizes we observed over the three years demonstrate that bowheads winter in small groups. Furthermore, the animals were not traveling in a consistent direction, which suggests they were overwintering and not engaged in a major movement (Figure 2-6).

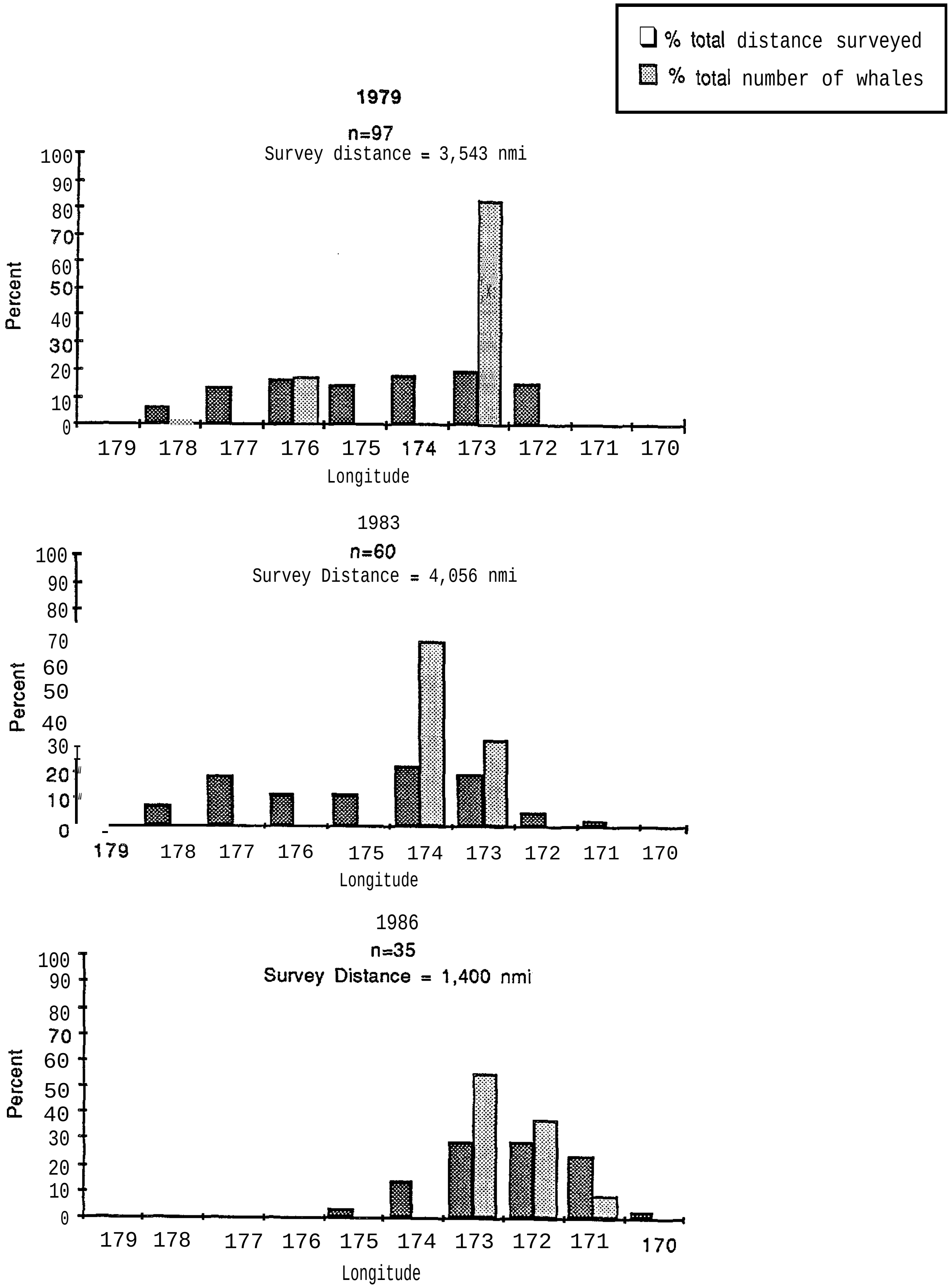

Figure 2-3. Survey effort and number of bowhead whales recorded at each longitude degree in the marginal ice front -1979, 1983, and 1986.

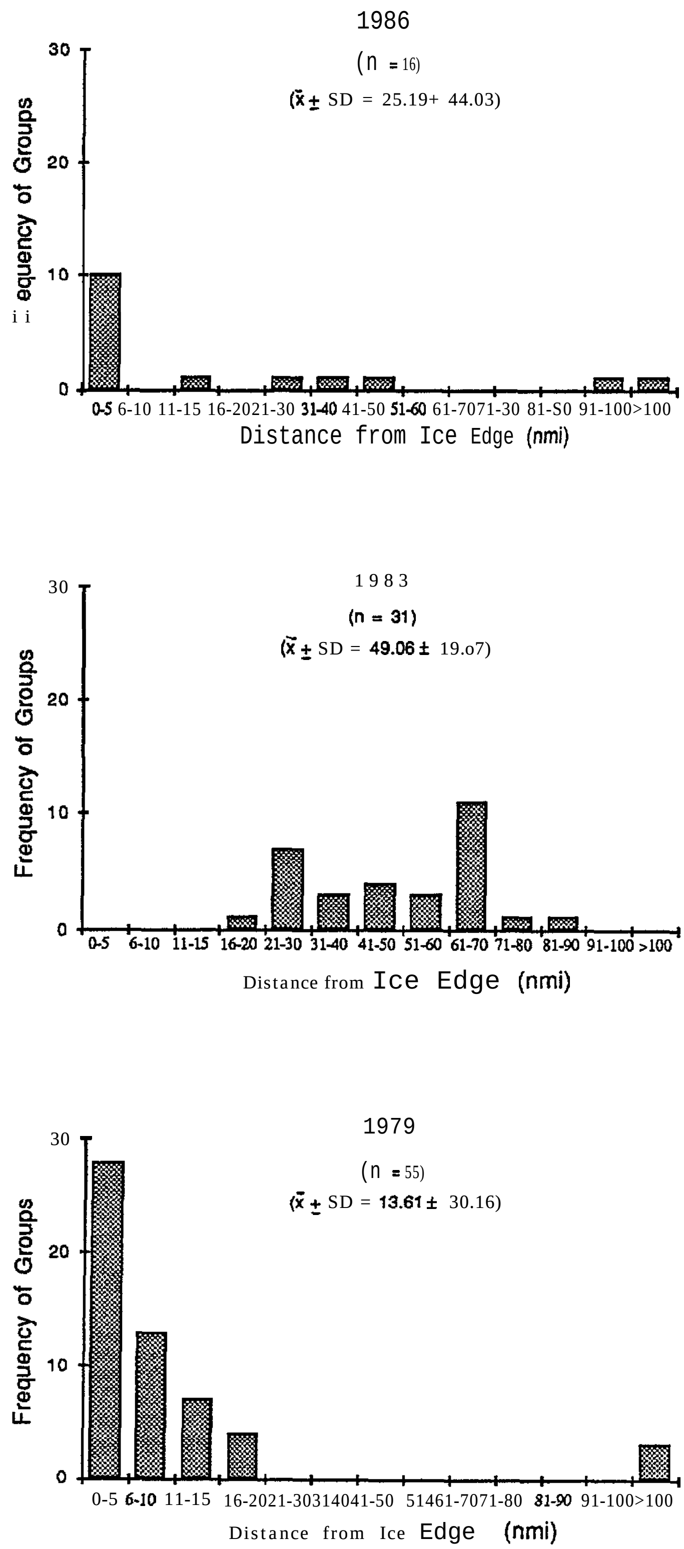

Figure 2-4. Frequency distribution of distances of bowhead whales from the ice edge into the pack ice--l 979, 1983, 1986.

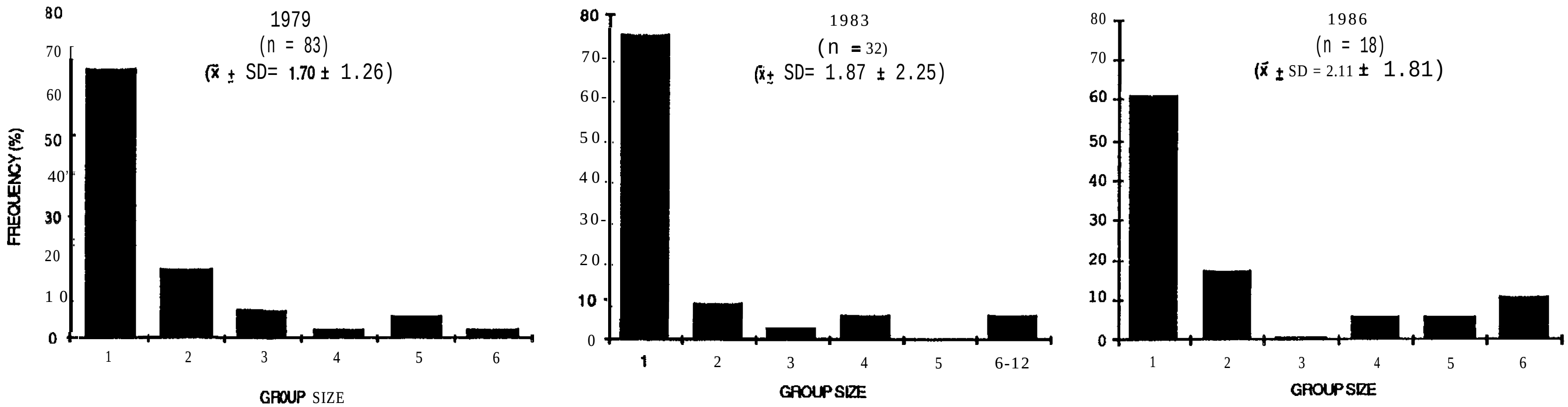

Figure 2-5. Percent frequency of bowhead whale group sizes observed in 1979, 1983, and 1986.

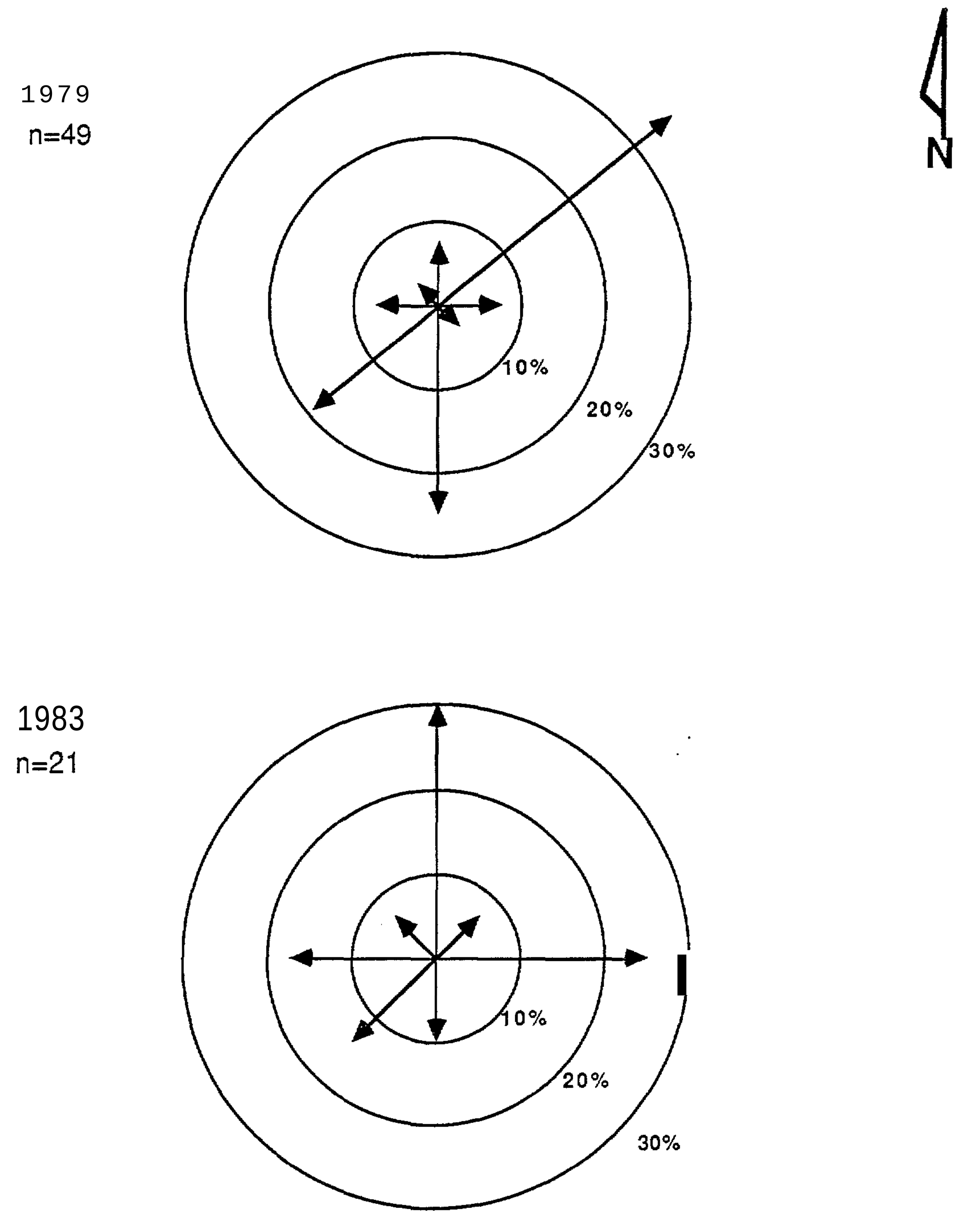

Figure 2-6. Directional orientation of bowhead whales in the study area during 1979 and 1983,

2.3.2 Ice Characterization

The pack ice of the study area was characterized by ice concentration and floe size for each of the three survey years (Tables 2-5, 2-6, 2-7). Ice concentration was adjusted to eliminate grease ice and to treat it as open water. Grease ice is an early stage of sea ice development. It was treated as open water for the following reasons: 1) grease ice is difficult to consistently distinguish from open water to accurately estimate ice coverage; 2) the ratio of grease to first year ice cannot be distinguished in an ice concentration category which combines these ice types into a single value of ice coverage (i.e., 55 to 65 percent ice concentration category could have 50 percent first year ice and 50 percent grease ice of the total ice or a variety of combinations which cannot be determined from the category); 3) bowheads are observable in grease ice from a survey platform but not first year ice; therefore, grease ice and open water within the pack ice are essentially identical for detecting bowhead whales; and 4) our analysis of the association of bowheads and the pack ice centered on the observability of the area available to bowheads from the survey platforms. Consequently, ice concentration estimates were adjusted for grease ice so that the categories were more comparable and suitable for analysis of bowhead occurrence. The biological implications of this modification are unclear since the data are insufficient to determine if bowhead whales equally use open water in the pack ice and grease ice.

The characteristics of the pack ice in the study area were generally similar among the three survey years except for the southern extension of the pack ice (Figure 2-l). The pack ice advanced approximately 90 nmi further south in 1983 than in 1979. The 1979 ice conditions were milder than average (Potocsky 1975). In 1979, the pack ice advanced until approximately the fourth week in March when the prevailing winds changed from northeast to south and pushed the pack ice northward (Salo et al. 1980). Conversely, the 1983 ice conditions were more severe than average (Potocsky 1975). The pack ice advanced until approximately the first week in April when a change in the prevailing wind direction initiated its northward retreat (Wilson et al. 1984). During both 1979 and 1983, the surveys at the marginal

Table 2-5. Ice characteristics of study area adjusted for grease ice, March - April 1979

Zone	Sampling unit	Percent area of ice	Percent area coverage of each ice concentration category											Percent area coverage of each floe size category			Total area surveyed (nm^2)
			0-5	5-15	15-25	25-35	35-45	45-55	55-65	65-75	75-85	85-95	95-100	Pancake-small	Medium-large	Vast-giant	
Northern	9	55.4	3.0	2.9	2.8	5.7	11.3	19.6	20.1	17.4	12.1	5.1	0.0	50.3	39.8	9.9	696.6
	10	42.1	2.0	8.3	13.1	15.8	16.2	14.9	14.2	10.0	4.9	0.6	0.0	49.9	38.0	12.1	548.1
	11	74.6	0.0	0.0	0.0	0.0	0.2	1.6	17.5	31.4	31.6	17.7	0.0	13.7	32.1	54.2	341.5
	12	73.9	0.0	0.5	0.6	0.9	1.8	4.6	11.8	26.6	31.2	22.0	0.0	6.8	25.3	67.9	348.0
Subtotal a/		58.4	1.6	3.6	4.8	6.7	9.0	12.4	16.5	19.4	16.9	9.1	0.0	31.9	34.4	33.7	1 934.2
Central	13	76.5	0.0	0.0	0.0	0.0	0.4	3.3	10.6	27.3	33.6	24.8	0.0	2.6	15.9	81.5	316.8
	14	78.8	0.0	0.0	0.0	0.2	0.5	0.5	5.1	26.8	37.4	29.5	0.0	0.2	8.7	91.1	369.2
	15	78.3	0.0	0.4	0.5	0.3	0.3	2.4	6.8	23.5	32.8	29.1	3.9	10.5	15.5	74.0	332.5
Subtotal a/		77.9	0.0	0.1	0.2	0.2	0.4	2.0	7.3	25.9	34.7	27.9	1.3	4.3	13.1	82.6	1 018.5
Southern	24	73.4	0.0	0.0	0.9	1.8	2.7	3.7	12.0	26.7	30.9	21.3	0.0	27.9	46.9	25,2	289.0
(Marginal	25	50.4	15.1	8.6	5.9	5.8	5.4	7.5	10.0	11.5	12.5	12.6	5.1	36.2	28.8	35.0	924.7
ice front)	26	48.1	2.9	2.0	6.5	13.6	20.4	18.7	14.8	11.5	7.0	2.1	0.5	93.2	6.3	0,5	809.7
	27	24.1	41.9	15.2	6.3	7.4	8.3	6.2	3.5	2.3	2.5	4.0	2.4	31.8	7.7	60.5	807.7
	28	54.7	1.2	3.9	6.5	9.0	11.0	12.8	18.5	18.5	13.5	5.1	0.0	20.8	28.1	51.1	712.2
Subtotal a/		46.6	14.4	7.0	5.8	8.2	10.4	10.5	11.5	12.1	10.7	7.4	2.0	44.1	23.6	32.3	3 543.3
Total		55.0	8.3	4.9	4.6	6.5	8.5	9.7	12.3	16.4	16.4	11.1	1.3	31.2	24.6	44.2	6496.1

a/ Mean values except for total area surveyed,

Table 2-6. Ice characteristics of study area adjusted for grease ice, February - March 1983

			Percent area coverage of each ice concentration category											Percent area coverage of each floe size category			Total
Zone	Sampling unit	Percent area of ice	0-5	5-15	15-25	25-35	35-45	45-55	55-65	65-75	75-85	85-95	95-100	Pancake-small	Medium-large	Vast-giant	area surveyed (nm^2)
Southern	24	65.9	9.9	0.7	1.2	1.2	1.7	5.5	9.0	21.7	33.1	16.0	0.0	6.3	4.8	88.9	213.6
	25	63.8	5.2	3.6	5.4	4.7	4.1	3.9	9.8	20.0	20.9	15.5	6.9	0.1	12.9	87.0	831.9
	26	62.7	6.8	3.4	3.6	2.7	6.6	9.6	7.6	16.1	22.8	15.7	5.1	5.7	19.8	74.5	1 027.9
	27	62.6	5.2	4.9	5.5	2.5	5.2	7.6	10.7	15.7	19.5	17.4	5.8	59.3	22.5	18.2	687.9
	28	51.2	19.0	9.7	1.4	0.9	2.5	6.3	14.1	18.2	14.7	9.6	3.6	24.8	33.8	41.4	886.2
	29	53.6	16.9	6.1	5.3	1.8	1.7	1.1	6.9	29.5	26.8	3.9	0.0	52.3	12.5	35.2	408.9
Total[a/]		59.7	10.1	5.2	3.8	2.5	4.3	6.3	10.0	18.9	21,0	13.4	4.5	22.1	19.9	58.0	4056.4

a/ Mean values except for total area surveyed.

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Table 2-7. Ice characteristics of study area adjusted for grease ice, January 1986

Zone	Sampling unit	Percent area of ice	Percent area coverage of each ice concentration category: 0-5	5-15	15-25	25-35	35-45	45-55	55-65	65-75	75-″85	85-95	95-100	Percent area coverage of each floe size category: Pancake-small	Medium-large	Vast-giant	Total area surveyed (nm^2)
Central	16	81.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.4	48.9	29.6	1.1	0.0	100.0	0.0	587.9
Southern	24	62.8	5.8	5.6	5.6	3.6	5.8	2.3	11.4	14.1	18.9	21.5	5.4	62,8	23.5	13.7	672.6
	25	47.6	18.7	15.8	1.3	3.1	6.1	5.2	8.4	7.6	15.9	16.9	1.0	99.1	0.9	0.0	620.4
	26	35.6	12.2	20.9	13.2	10.0	10.8	5.2	7.3	7.4	6.5	6.5	0.0	100.0	0.0	0.0	111.2
	27	28.1	0.0	0.0	34.5	50.0	15.5	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	16.7
Subtotal		53.6	11.8	11.3	4.6	4.4	6.5	3.7	9.6	10.6	16.4	18.1	3.0	79,2	13.3	7.5	1 420.9
Total[a/]		61.7	8.4	7.9	3.3	3.1	4.6	2.7	6.8	13.4	25.9	21.5	2.4	49.5	45,8	4.7	2008.8

a/ Mean values except for total area surveyed.

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ice front were conducted before the pack ice retreated and when it was at or near its maximum southern extent. The 1986 surveys were conducted during January, considerably before the pack ice completed its southern advance. The 1979 surveys of the northern and central zones were conducted when the pack ice was retreating, but the ice edge location was considerably south of the survey areas. We can, therefore, generally conclude that the 1979, 1983, and 1986 surveys were conducted before spring breakup when most bowheads were wintering in the Bering Sea.

Ice coverage in the study area was highest in the central zone, lowest in the marginal ice front, and intermediate in the northern zones (Tables 2-5, 2-6, 2-7). The central zone had about 80 percent ice coverage in both 1979 and 1986. Ice coverage was consistently high across this zone which featured large proportions of area in the higher ice concentration and floe size categories (Figure 2-7). These characteristics show that this was a transition zone of extensive ice between the more dynamic northern zone and marginal ice front. The marginal ice front had between 45 and 60 percent ice coverage during the three survey years. Ice coverage consistently decreased from east to west across the front between units 24 and 27, especially during the less extreme ice years of 1979 and 1986. The ice coverage pattern was very broken and it featured relatively equal proportions of area in a wide variety of ice concentration and floe size categories. These characteristics are primarily shaped by the action of the open ocean on the front but also by the presence of St. Matthew Island and its associated polynya. Ice coverage in the northern zone was also broken, but less than in the front. The northern zone had approximately 60 percent ice coverage, which generally increased from east to west. Ice coverage in this zone featured a wide variety of ice concentration and floe size categories that had larger proportions of area in higher categories than observed in the front. St. Lawrence Island, the northern Gulf of Anadyr and their associated polynyas, and the highly active Straits of Anadyr between these land masses greatly influenced the ice coverage patterns observed in this zone. These results show that the pack ice in the northern zones and front was very broken and provided more open water for bowheads compared to the much more compacted central zone.

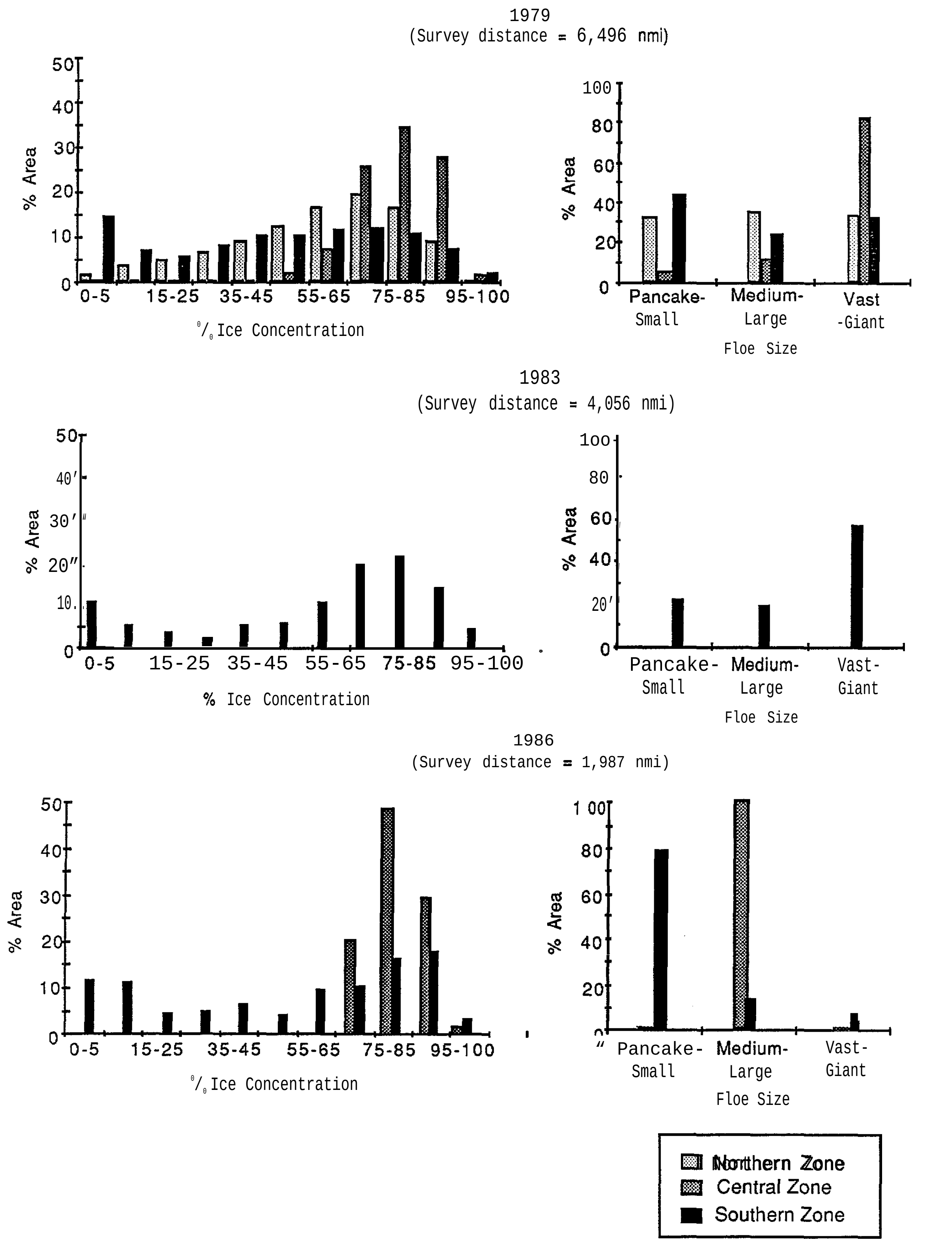

Figure 2-7. Percent area coverage of each ice concentration and floe size category in the study area 1979, 1983 and 1986.

2.3.3 Bowhead Association with Sea Ice

Bowhead whales were associated with a variety of ice conditions located in areas having persistent proportions of open water that were primarily near polynyas. During the three survey years, bowheads occurred in essentially every ice concentration category comprising the pack ice (Figure 2-8). The whales, however, were not distributed in proportion to the availability of open water in each category ($p<0.05$). The observed number of bowhead groups was generally lower than expected for the 0 to 45 percent ice concentrations but higher than expected for the 55 to 95 percent ice concentrations. Approximately 55 percent of the 133 groups were associated witn the 55 to 85 percent ice concentrations (Table 2-8). In the other concentrations, the observed number of groups approximately equaled the expected number in the 45 to 55 percent ice concentration category while no whales were seen in the 95 to 100 percent category since it was predominantly ice covered. There were no whales seen south of the pack ice in the open ocean nor were there whale vocalizations heard in the open water during 1986 when 10 sonobuoys were deployed between the Pribilof Islands and the pack ice.

Bowheads occurred in areas of the pack ice where there was a persistent proportion of open water (Table 2-Y). Persistence was defined as the category with the highest frequency of occurrence. The locations of 126 cells that either contained a bowhead sighting or were randomly selected from the survey trackline were examined from NOAA satellite imagery to determine the persistence of open water over time. Cells or areas of persistent mixed or open water were assumed to be attractive to bowhead whales. A 15 to 30-day window centered around the date a cell was surveyed represented the time frame for selecting the imagery to evaluate persistence. Between 4 and 10 days of usable satellite images were available for each cell. Chi-square analysis of a two by three contingency table comparing cells with and without bowheads to persistence of water showed that the hypothesis of independence was rejected ($p<0.05$). The observed number of cells with whales exceeded the expected values for ice conditions with persistent mixed or open water, whereas the reverse was the case for cells without whales.

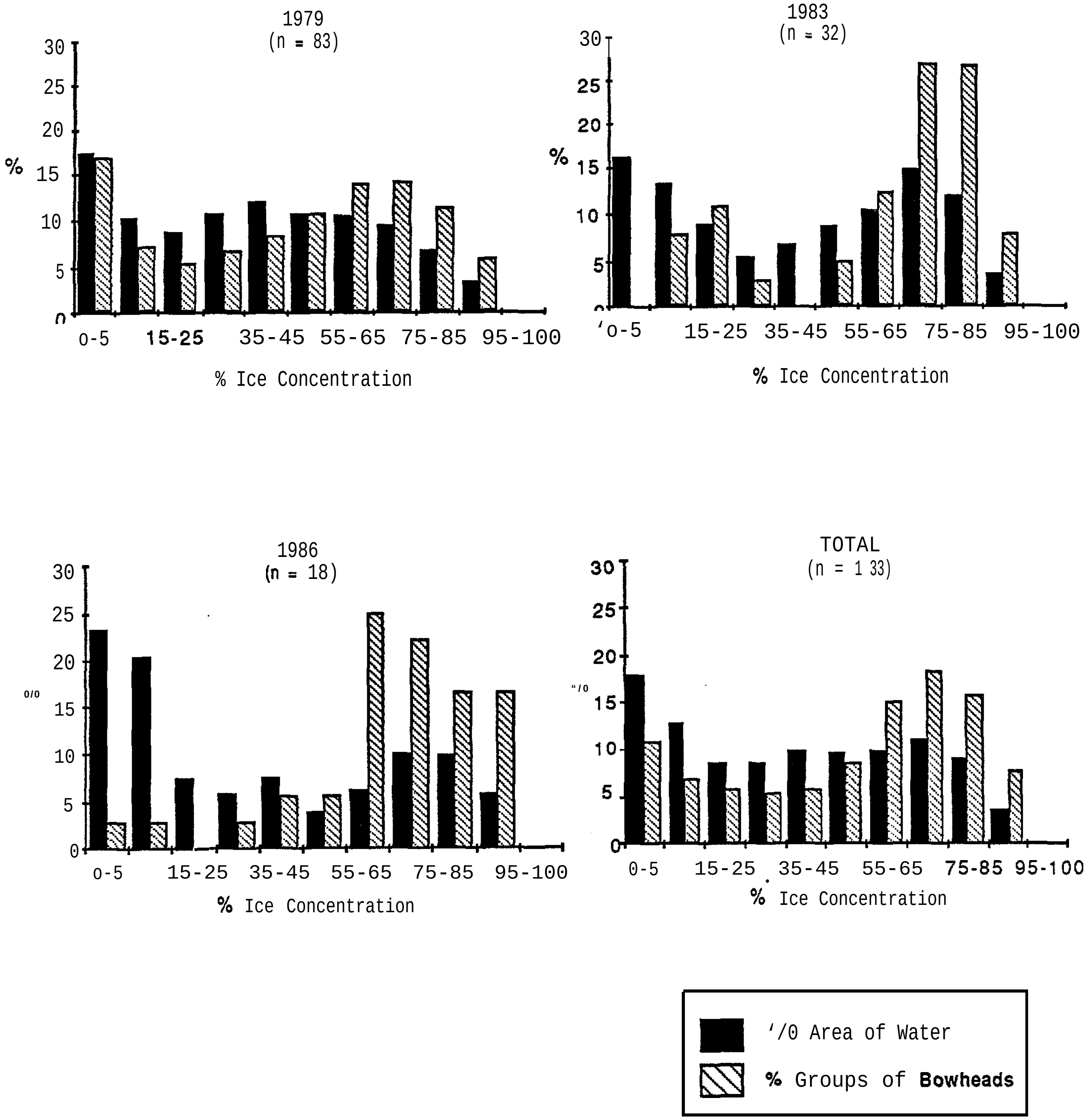

Figure 2-8. Percent of water and percent of bowhead whale groups occurring in the Bering Sea pack ice 1979, 1983, 1986.

TABLE 2-8

PERCENT OF BOWHEAD WHALES RELATIVE TO PERCENT OF TOTAL OPEN WATER AVAILABLE IN EACH ICE CONCENTRATION CATEGORY OF THE STUDY AREA, 1979, 1983, AND 1986

	1979		1983		1986		Total	
Ice Concentration Category	Percent[a/] Open Water	Percent Number Groups	Percent Open Water	Percent Number Groups	Percent Open Water	Percent Number Groups	Percent Open Water	Percent Number Groups
o - 5	17.4	16.9	16.2	0.0	23.2	2.8	17.9	10.9
5 - 15	10.2	7.1	13.3	7.8	20.5	2.8	12.6	6.7
15 - 25	8.7	5.2	8.9	10.9	7.5	0.0	8.6	5.9
25 - 35	10.7	6.8	5.2	3.0	5.8	2.8	8.4	5.4
35 - 45	12.1	8.1	6.8	0.0	7.5	5.6	9.8	5.8
45 - 55	11.3	10.6	8.7	4.7	3.9	5.6	9.5	8.5
55 - 65	10.3	14.0	10.3	12.5	6.2	25.0	9.7	15.1
65 - 75	9.3	14.2	14.9	26.7	9.9	22.2	11.0	18.3
75 - 85	6.8	11.3	12.1	26.6	9.8	16.6	8.8	15.7
85 - 95	3.2	5.8	3.6	7.8	5.7	16.6	3.7	7.7
95 - 100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total Groups	--	83	--	32	--	18	--	133
Total Distance (nmi)	2,601.7	--	1,380.5	--	675.4	--	4,657.6	--

a/ Percent open water equals the proportion of the total open water (including grease ice) distance surveyed in each ice concentration category.

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TABLE 2-9

OBSERVATION FREQUENCY OF THREE CATEGORIES OF SEA SURFACE CONDITIONS IN THE STUDY AREA FOR LOCATIONS WITH AND WITHOUT WHALES

Whale Present/Absent	Sea Surface Category a/			
	Closed	Open-Mixed	Open Ocean	Total
Cells with Whales	3 (9) c/	74 (62)	2 b/ (8)	79
Cells without Whales	12 (6)	25 (37)	10 (4)	47
Total	15	99	12	126 d/

a/ Closed = 100 percent frozen, open-mixed = ice free to mixed with sea ice, and open ocean = south of pack ice.

b/ Cells with whales in the open ocean category were in the pack ice near its southern terminus. Their inclusion in the open ocean was due to the interpretation of the position from the satellite photo images.

c/ Parenthesis signify expected value.

d/ Calculated x2 = 28.7.

Approximately 95 percent of the cells with whales were ranked in the mixed and open water categories while 51 percent of the nonwhale cells were ranked in these categories. These results suggest that while whales were associated with a variety of ice conditions, the locations were in areas of the pack ice where mixed to open water were more persistent than those found for a set of randomly selected nonwhale locations.

Since these results demonstrated that bowhead distribution was influenced by ice concentration and persistence of mixed to open water in the pack ice, these variables were incorporated into regression equations to predict 1) presence or absence of bowheads in the pack ice and 2) number of groups per nautical mile if whales were present. The presence or absence analysis was conducted in two phases. The entire data base without persistence information was initially used to test the relationship between ice concentration and presence or absence of whales. The regression was, however, not significant and the r^2 (0.005; cv = 541 percent) was low because of the large number of segments without whales (3,291 segments without whales, 112 segments with whales). A second analysis was conducted for 581 segments that were in 126 cells evaluated for persistence of open water. There were 111 whales in 79 cells and470 trackline segments without whales in 47 cells. Persistence was expressed as the percent of total days of usable imagery according to each of the six categories described on page 2-16. The persistence of water variable was included with the ice concentration variable. The regression was not significant but the r^2 (0.059; Cv = 200 percent) increased 12 times above that of the initial analysis. The first variable selected in the forward stepwise regression was persistence of percent mixed ice (MP) and the second variable was the arcsine of the percent area of water adjusted for grease ice for ice concentration (CGWA). The inclusion of the second variable increased the r^2 from 0.027 to 0.059. The resulting equation for predicting number of groups (N) was:

$$N = 0.0023 + 0.5 * MP + 0.0034 * CGWA.$$

While the relationship is not conclusive, it is suggestive that areas in the pack ice with a persistent mix of ice and open water influenced the bowhead distribution in the Bering Sea.

Given that whales were present, a regression equation was developed to predict the number of bowhead groups per nautical mile of open water from ice concentration and persistence of open water in the pack ice. A forward stepwise regression analysis selected two forms of the variable concentration but not persistence of open water. The r^2 increased from 0.31 (cv = 99 percent) for the arcsine of the percent area of ice adjusted for grease (CGA) in a given ice concentration category to 0.41 (cv = 92 percent) for the percent area of water adjusted for grease (CGWTR) in a given ice concentration category. The resulting equation for predicting number of groups per nmi (NPN) was:

$$NPN = -21.2 + 0.38 * CGA + 21.7 * CGWTR.$$

The r^2 values calculated for each survey year from these variables were 0.47 (Cv = 95 percent) for 1979, 0.45 (cv = 84 percent) for 1983, and 0.69 (cv = 46 percent) for 1985.

2.4 DISCUSSION

In this study, equations were developed to predict both bowhead whale density and presence/absence of the whales from a variety of ice parameters. The coefficients of variation and the confidences interpreted for such predictive equations were, however, extremely large and the results may not be useful for management purposes. Results are in part inconclusive due to the number of observations on which the analyses were based, as well as the small number of whales signted within these observations. The results were, however, suggestive that ice concentration is probably a variable influencing bowhead distribution in the pack ice of the Bering Sea and that the persistence of some open water in the pack ice may influence the geographic areas inhabited by bowheads. While the capability to predict bowhead distribution from ice conditions is inconclusive, the results of the study provide the most comprehensive description of bowhead whale occurrence in the Bering Sea pack ice since Townsend (1935) charted the commercial catch distribution.

The results show that bowheads were widespread in the pack ice, but they were more confined in the marginal ice front. i30whead distribution in the marginal ice front was very clumped in 1979 and 1983 when intensive surveys were conducted across a broad swath of the front. The majority of the whales observed in 1979 and all the whales observed in 1983 were in the vicinity of St. Matthew Island. Moreover, a proportion of the two bowhead distributions overlapped. The whales occurred primarily as singles, distributed in a northeast-southwest direction west of St. Matthew Island. Whales inhabited this area when the pack ice was present irrespective of the location of the ice "edge" which was considerably farther south of St. Matthew Island in 1983 than in 1979. Their locations corresponded to the western border of the St. Matthew Island polynya. The St. Matthew Island polynya was visible on satellite images covering 17 percent of the days between February and April 1983 (Table 2-10). The minimum size of the polynya visible in the images averaged over approximately 300 nmi^2 during these months. Although the island vicinity was obscured by clouds most of the time during these months in 1979 and 1983, the polynya is normally present throughout the winter when the prevailing northeast winds blow the ice away from the island.

Bowhead distribution was more widespread in 1986 when the ice front was north of St. Matthew Island, but the whales occurred in a band of longitudes bracketing St. Matthew Island. The advance of the pack ice south would have almost certainly pushed these whales into the vicinity of St. Matthew Island. These results and those of 1979 and 1983 strongly suggest that bowheads move south with the advance of the pack ice from St. Lawrence Island to the vicinity of St. Matthew Island where a substantial number winter near the polynya. The importance of this area is corroborated by sightings by Burns (unpublished data) of three groups of five bowheads west (2) and north (1) of St. Matthew Island on 4 and 8 April 1971. Hanna (1920) reported furthermore that

TABLE 2-10

DAYS (N) OF USABLE NOAA SATELLITE IMAGERY AND MINIMUM AVERAGE ($\bar{x}$ ± SD) SIZE (nm^2) OF THE POLYNYAS AT ST. MATTHEW ISLAND, ST. LAWRENCE ISLAND, AND THE NORTHERN GULF OF ANADYR[a]/

Polynya Location and Year	January			February			March			April		
	N	$\bar{x}$ ± SD	Range	N	$\bar{x}$ ± SD	Range	N	$\bar{x}$ ± SD	Range	N	$\bar{x}$ ± SD	Range
St. Matthew Island												
1979		---			---		3	147 ± 72	101 - 230		---	
1983		---		4	272 ± 106	199 - 424	9	432:696	87 -2,250	4	985:852	54 - 1,710
1986		---			---			---			---	
St. Lawrence Island												
1979		---		15	1,346 + 774	256 - 3,105	15	952:637	322 - 2,468	8	2,646 ± 1,644	682 - 5,431
1983	10	605 ± 252	275 - 1,085	Y	673:217	402 - 991	15	1,188 ± 1,008	169 - 3,476	8	1,045:503	527 - 2,021
1986	21	723 ± 636	147 - 3,121		---			---			---	
Gulf of Anadyr												
1979	5	880:784	397 - 2,268	13	808:574	110 - 1,759	23	1,024:388	473 - 1,802	17	5,921 ± 5,708	790 - 25,715
1983	9	2,260:1,567	579 - 4,938	8	1,071 + 585	158 - 1,768	16	2,275:1,235	500 - 5,367	11	2,229:1,210	385 - 4,427
1986	22	1,296 + 1,206	220 - 5,575		---			---			---	

a/ Polynya area was delineated on NOAA satellite imagery and digitized into a computer which rectified the images to a USGS base map and calculated the area. Polynya sizes represent minimum area since frequently the polynya was partially obscured by clouds. The sample sizes (N) represent essentially all the usable imagery for each month. Only January was examined in 1986.

large numbers of bowhead whale bones were scattered along the beach of St. Matthew Island during a survey in 1916. Our results in conjunction with others identify the importance of the St. Matthew Island vicinity where the polynya probably serves as a refuge to bowheads from heavy ice since open water or water covered with thin ice (new ice) are always available when the pack ice is present (Stirling and Cleator 1981).

Whales also occurred elsewhere in the marginal ice front but our observations suggest the numbers are much smaller then around St. Matthew Island. Most whales historically and more recently occurred between Cape Navarin and St. Matthew Island, although Leatherwood et al. (1983) recently reported a bowhead southeast of the island in the front. A reason for the disparity of bowhead occurrences across the front is unclear but whalers historically hunted much more intensely in the front near Cape Navarin than at St. Matthew Island (Bockstoce and Botkin 1983). If the social structure of the bowhead population is organized for young animals to learn range location by following older more dominant animals as is found in many species of ungulates (Giest 1971), then the higher occurrence of bowheads at St. Matthew Island may derive from a larger number of older whales that were not harvested from the population and have maintained traditional use of the area.

In addition to the marginal ice front, substantial numbers of bowhead whales occurred in the northern zone, south and west of St. Lawrence Island and less frequently in the central zone. Whales were spread across the northern zone in 1979. Since this was the only year the northern zone was surveyed, the pattern of use could not be corroborated. Surveys by Russian scientists (Bogoslovskaya and Votrogov 1981, Bogoslovskaya et al., 1982) and observations by the Siberian Eskimos identify that the northern Gulf of Anadyr has been traditionally inhabited by bowheads during the winter and spring. This area contains a large polynya that recurs each year. Furthermore, whalers historically reported whales in this area and the St. Lawrence Island vicinity (Aldrich 1889, Cook 1926, Bodfish 1936, Tomilin 1957).

Whales are also known to winter and migrate near St. Lawrence Island where Eskimos continue to annually hunt them. Whales occurring near St. Lawrence Island were associated with the St. Lawrence polynya. The St. Lawrence Island polynya was visible on NOAA satellite imagery covering 43 percent of the days between February and April 1979 and 35 percent of the days between January and April 1983 (Table 2-10). The minimum area of the polynya visible in the image, while quite variable, averaged over 600 nmi^2. The northern Gulf of Anadyr polynya was visible 48 percent and 38 percent of the days between January and April 1979 and 1983, respectively (Table 2-10). The minimum area visible on the images, while quite variable, usually averaged over 900 nmi^2. Cloud cover obscured both of these polynyas most of the time and frequently precluded determining their absolute daily sizes from the images. These polynyas, like the St. Matthew Island polynya, are consequently present each year and probably provide a refuge for bowheads from the heavy pack ice during winter and spring.

The few whales observed in the central zone in 1979 and 1986 were widely spaced. During 1979, the whales were closely associated with those seen south of the northern coast of the Gulf of Anadyr. The whales observed in 1986 were considerably south of the St. Lawrence Island polynya, in relatively heavy ice. The few whales observed in the central zone may be due to the small amount of open water available for seeing whales from a survey platform. In addition, this general area of pack ice between St. Lawrence and St. Matthew Islands characteristically features areas of extensive and heavy ice (Potocsky 1975) that do not provide consistent areas of open water for whales to inhabit during March/April when ice is at its maximum extent and development.

In general, the results of these studies show that bowhead distribution is associated with areas having very dynamic ice conditions. The ice conditions around St. Lawrence Island, St. Matthew Island, and the northern Gulf of Anadyr include recurring polynyas while the area between St. Lawrence Island and the Gulf of Anadyr is in the highly active Strait of Anadyr. Moreover, the marginal ice front is very dynamic because of its close association with the open ocean and the associated wave action on the pack ice. Because of the high activity in these areas, they feature a variety of ice conditions. That variety corresponds to the variety of ice concentrations associated with bowhead whales. The broken features of these areas coupled with a dependability of open water provide bowheads a refuge in the pack ice.

2.5 SUMMARY AND CONCLUSIONS

The distribution and association of bowhead whales in the pack ice of the Bering Sea were determined from three data bases. The data bases had 83 groups of 141 bowheads in 1979, 32 groups of 60 bowheads in 1983, and 18 groups of 38 bowheads in 1986. A total of almost 12,561 nmi were surveyed in the pack ice from vessel and aircraft during these years.

The results demonstrated that bowhead whales were widespread in the pack ice. Bowheads inhabited the marginal ice front during each of the three survey years. Their numbers were relatively high in the vicinity of St. Matthew Island. Whales were more evenly distributed in the northern zone of the study area which included St. Lawrence Island, the Straits of Anadyr, and the northern Gulf of Anadyr. These areas have very dynamic ice conditions and they feature more broken ice and persistent open water than in the central zone where few whales were observed. Bowheads were correlated with a variety of ice concentrations which reflects the broken ice characteristics of the northern and southern zones. Because bowheads were associated with sea ice, regression equations were formulated to predict presence or absence and density of bowhead whales in the various ice concentrations comprising the pack ice. Small sample sizes, however, contributed to low r^2 values and high coefficients of variation for the equations. Consequently, the capacity to mathematically predict bowhead whale association with sea ice was inconclusive.

There are several important conclusions from this study which provide guidance for MMS to manage petroleum operations in the Bering Sea when bowheads are present. The pack ice around the St. Matthew Island vicinity is an important wintering area for bowhead whales. The whales appear to access this area by passively moving with the advances of the pack ice. Consequently, a band of pack ice between St. Matthew and St. Lawrence islands appears to be one possible movement corridor during the fall and spring. This area should be recognized as a potentially sensitive area for bowhead whales. Based on our observations, few whales appear to advance with the pack ice beyond the southern extreme of the St. Matthew Island area. The pack ice near St. Lawrence Island and west into the northern Gulf of Anadyr appears to also be an important wintering area. Historic records indicate that both these areas and the St. Matthew Island area have been traditionally used by whales during winter. While these areas may be sensitive to development, whales are obviously also scattered elsewhere throughout the pack ice. This represents a more difficult management problem that will require careful consideration. The areas east of St. Lawrence and St. Matthew islands appear to receive much lower use by bowheads throughout the wintering period because the pack ice is generally heavy and very compacted.

3.0

SEA ICE MONITORING METHODS

3.0 SEA ICE MONITORING METHODS

3.1 CHARACTERISTICS OF POTENTIAL MONITORING SYSTEMS

3.1.1 Introduction

This section presents a comparative analysis of the current and potential methods of observing sea ice conditions in the Bering Sea to indirectly monitor or predict the presence of bowhead whales. The analysis consisted of, first, identifying those systems capable of sea ice detection with current or potential application in the Alaska area and, secondly, evaluating the effectiveness of each of these systems in monitoring the sea ice margin pursuant to specified operational criteria. The systems identified as having ice observation capabilities consisted of two categories: remote sensing and surface-based observations. In the context of-this section, remote sensing is restricted to methods which record electromagnetic radiation reflected or radiated from an object (Spencer and Krebs 1981). Nearly all of the systems described in this section use the technology of remote sensing for ice observation and include satellites and airborne/surface radar. Surface-based marine observations are basically "point" observations, more-or-less continuous along a "line" from moored or drifting buoys, or visual observations from aircraft.

Tables 3-1 and 3-2 enumerate the ice monitoring systems evaluated in this section. These systems were initially selected by virtue of their current and potential ability to detect some parameter of the ice cover.

The effectiveness of each technique in providing ice information relavent to monitoring the winter presence of bowhead whales in the Bering Sea were evaluated in terms of their capabilities in detecting the morphology of the sea ice edge (including drift rate) and the timeliness and method of data relay to government officials (Minerals Management Service) for monitoring purposes.

TABLE 3-1

CURRENT ICE MONITORING SYSTEMS AND GENERAL CAPABILITIES

1. Satellites:	
a. Advanced TIROS-N (NOAA) (1.0 km)a/ scanning radiometer (HPRT broadcast: 1.1 km)	ice extent/internal geometry/inferred ice age
b. Nimbus 7 passive microwave radiometer (25 km)a/	1st yr ice extent
c. Landsat 4 and 5 visible/infrared radiometers (80 m)	Ice extent/internal geometry/some topography
d. Geosat (1985-88) radar altimeter (8 cm)	sea ice-water boundary
2. Airborne:	
a. Visual	subjective mapping of most ice features
b. Real Aperture Radar (Side Looking Radar) (30-400 m)	ice-water boundaries/ flow sizes/leads/some topography/some ice age
c. Synthetic Aperture Radar active microwave (6-12 m)	same as 2.b
d. Marine Radar pulse compression	ice-water boundary individual targets
3. Rig- Land- Ship-Based Radar	ice target detection ice target velocities

a/ Measurement in parentheses signifies spatial resolution of system.

TABLE 3-2

FUTURE ICE MONITORING SYSTEMS AND GENERAL CAPABILITIES

1. Satellites:	
a. NOAA H-M (through the '90s) visible/infrared radiometers	same as present series
b. Defense Military Sate" lite Program (DMSP) (1987- mid 90's) passive microwave rad' ometer (25 km)	ice edge/ice cover/1st year ice vs. old ice
c. ERS-1 (1989-92) synthetic aperture radar (30 m)	ice edge/internal geometry topography inferred ice types/thickness/physical properties
d. Radarsat (1990) 1. synthetic aperture radar (26 m) 2. advanced very high resolution radiometer-visible/IR (1.1 km) 3. modular optoelectronic multi-spectral scanner (30 m)	same as 1.c
e. J-ERS-1 (1991) synthetic aperture radar	same as 1.c
f. Alpha and Beta Polar Platforms (early -mid 1990's) synthetic aperture radar microwave radiometer radar altimeter	Alpha, same as 1.b and l.c. Beta, same as lb.
2. Point Observations:	
a. Sonobuoys echo sounding	pack ice-present/absent possible ice properties requires research
b. Moored buoys submergible buoys	pack ice-present/absent possible ice coverage requires development

a/ Measurement in parentheses signifies spatial resolution of system.

3.1.2 Methods

The operational criteria against which the systems' capabilities are compared are based on requirements established by MMS for an effective ice monitoring system. An effective ice monitoring system must be capable of detecting those ice characteristics significantly associated with bowhead whale habitat while allowing near-real time accessibility of the information by the users. A discussion of each of the operational criteria follows.

Ice Characteristics

The results in Section 2.0 show that bowhead whales are associated with a variety of ice conditions. The whales were observed in essentially every ice concentration category and they were widespread in the pack ice. Areas of the pack ice-where bowheads were most commonly observed featured a mosaic of broken ice combined with a persistence of open water or open water mixed with sea ice. These two sea surface conditions were evaluated according to their presence or absence in 6 x 6 nmi cells examined from satellite imagery. Other ice characteristics considered included floe size and ice thickness. Floe size, however, was not an independent variable because it increased in size with increasing ice concentrations. Ice concentration was felt to be a better measure for judging whale association with sea ice. Ice thickness was evaluated because bowheads were observed in grease ice. Their occurrence in the more advanced ice thickness stages was not examined because observers could not detect whales in young or older ice. A full discussion of these results is given in Section 2.0.

While the results in Section 2.0 show only broad relationships between bowhead whales and sea ice, the following ice characteristics must be detectable for an ice monitoring system to effectively identify areas likely to be associated with bowhead whales.

- Extent of pack ice - the presence of pack ice in the Bering Sea between November and June signals the associated occurrence of bowhead whales. The southern margin of the pack ice or ice edge must be detectable to within a 1 km resolution from an ice monitoring system to determine the pack ice extent.

- Presence of water in pack ice - ice concentration combines ratios of water to sea ice cover. Since whales were observed in ice concentrations ranging between 5-15 percent and 85-95 percent ice coverage, an effective ice monitoring system must be able to detect ice concentrations (0-100 percent) comprising the pack ice.

- Presence of grease ice - grease ice, an initial stage in the development of sea ice, was treated as open water in the Section 2.0 analysis of ice concentration. Bowheads were observed in grease ice ($\leq$ 5 cm thick). Since there can be large continuous areas of grease ice in the pack ice (i.e., polynyas), they must be detectable from an ice monitoring system to effectively identify potential bowhead whale use areas.

Consequently, the system must be able to detect the ice edge, ice concentration, and grease ice (from older stages of ice development) to be effective for monitoring potential bowhead whale use areas. While these characteristics were used to evaluate ice observation systems, the capabilities of each ice observation system examined were defined according to a comprehensive suite of sea ice characteristics. These systems could then be reexamined relative to advances in defining the association of bowhead whales with sea ice.

The capabilities of the currently available and future ice observation systems are given in Tables 3-3 and 3-4. Only ice features relevant to the Navarin Basin environment (landfast ice or multiyear ice were not

TABLE 3-3
CAPABILITIES OF CURRENT SYSTEMS
IN DETECTING CHARACTERISTICS OF THE BERING SEA ICE COVER

	NOAA Visual	Series IR	Nimbus 7 SMMR	Landsat MSS	Geosat (Altimeter)	Comments
Ice Concentration:						
Open Water (10%)	X	X		X		
Very Open Pack (10-30%)	X	X	X	X		
Open Pack (40-60%)	X	X	X	X		
Close Pack (70-80%)	X	X	X	X		
Very Close Pack (90% 100%)	X	X	X	X		
Compact Pact (100%)	X	X	X	X		
Ice Thickness Inferred by Age:						
New Ice[a]	X	X		X		
Frazil (5cm)						
Grease (5cm)						
Slush (5cm)						
Shugu (5cm)						
Dark Nilas (5cm)						
Light Nilas (5-10cm)						
Ice Rind (5cm)						
Pancake (10cm)						
Young Ice	x	X		X		
Gray (10-15cm)	X	X		X		
Gray-White (15-30cm)	X	X		X		
First Year Ice (30-120cm)	X	X	X	X		
Thin First Year (30-50cm)						
Medium First Year (70-120cm)						
Thick First Year (120cm)						
Forms of Floating Ice (Diameter):						
Pancake (3m)						
Brash (2m)						
Ice Cake (20m)						
Small Floe (20-100m)	X[b]	X[b]				
Medium Floe (100-500m)	X[b]	X[b]				
Big Floe (500m-2km)	X	X				
Vast Floe (2-10km)	X	X				
Giant Floe (10km)	X	X				
Ice Edge:	X	X				
Compacted	X	X				
Diffuse	X	X				
Ice limit						

TABLE 3-3 (Continued)
CAPABILITIES OF CURRENT SYSTEMS
IN DETECTING CHARACTERISTICS OF THE BERING SEA ICE COVER

	NOAA Visual	Series IR	Nimbus 7 SMMR	Landsat Mss	Geosat (Altimeter)	Comments
Pack Ice Deformation:						
Finger Rafting						
Rafting						
Ridging				X		major zones
Fracturing				X		major zones
Hummocking						
Pack Ice Motion Processes:						
Shearing	X	X		X		by sequential images
Compacting	X	X		X		by sequential images
Diverging	X	X		X	-	by sequential images
Ice Surface Features:				X		some
Level Ice						
Rafted Ice						
Ridged Ice						
New Ridge						
Weathered Ridge						
Very Weathered Ridge						
Aged Ridge						
Consolidated Ridge						
State of Melting:	X	X		X		inferred through other features
Puddled						
Thaw Holes						
Dried Ice						
Rotten Ice						
Flooded Ice						
Openings in the Ice:						
Polynyas	X	X	X	X		resolution limited
Fracture				X		
Fracture Zone				X		
Leads	X	X		X		resolution limited

a/ New ice is inferred through other fractures.
b/ Floe categories are inferred through tonal appearance.

included) were considered in the evalution. In addition, the capacity of an observation system to detect classes of ice thickness was based on distinguishing the ice development stage or age (i.e., gray vs. white ice). Although short pulse radar (microwave systems) has been shown to measure ice thickness accurately to 5 cm from altitudes up to 2 kilometers (Schertler et al. 1975), there are no fully operational systems in current use (Inkster, personal communications). The sea ice nomenclature used in this section follows that of the World Meteorological Organization (WMO) which is based on ice morphology (Dunbar 1969).

Operating Capacity

An effective ice monitoring system, or combination of systems, is required to operate day and night in all weather conditions between December 1 and May 31.

Operational Frequency

Ice observations must be made frequently enough to allow time to issue a warning when rapidly moving sea ice is still 220 km from the oil and gas platforms and moving at a maximum rate of 80 km per day. The minimal observational frequency was decided to be once per day once the ice edge moved to within 300 km of a platform and continued advancing southward at an 80 km/day rate.

Notification Procedure

The monitoring system must provide reports of the position and rate of movement of the ice cover to the Minerals Management Service, Regional Supervisor for Offshore Field Operations, Alaska OCS Region, and to field officials of the oil and gas companies within 3 hours of observation.

3.1.3 Results and Discussion

3.1 .3.1 Examination of Ice Observation Techniques (Current Capabilities)

Satellites:

TIROS Polar-Orbiting Environmental Satellites (NOAA Series) - The Advanced Very High Resolution Radiometer (AVHRR) on the NOAA satellite series provides visual and thermal infrared imagery (TIR) of sea ice conditions at 1 km resolution (NESDIS 1985). Current practice is to maintain two satellites in orbit, therefore providing morning and afternoon observations of the Bering Sea with track scans measuring nearly 3000 km across. Visible imagery is used for ice analysis during the spring period while infrared imagery is useful during the winter when low light conditions predominate. The presence of clouds precludes routine observation of the ice conditions.

The data are broadcast in real time to both Automatic Picture Transmission (APT) and High Resolution Picture Transmission (HRPT) users (NESDIS 1984). In the Alaska area the AVHRR data are received at the NOAA-managed Command and Data Acquisition Center at Gilmore Creek. The data are recorded and retransmitted via satellite to Suitland, Maryland for central processing. The data are routed to NOAA's National Weather Service Forecast Offices in Fairbanks and Juneau via dedicated terrestrial communication circuits for local processing. The satellite imagery is distributed to commercial users through either the GOES-TAP (TAP signifies the capability of the system to tap into various programs) Program or WSFO-TAP Program. The customers are responsible for providing their own terminal display equipment, acquiring appropriate telephone communications, signing an agreement with the government and, for the GOES-TAP, paying both an initial connection and annual service fee.

Interpretation of the NOAA satellite imagery by experienced analysts and digital enhancements of the infrared imagery permit the delineation of several characteristics of the ice cover (McNutt 1981, Mullane 1978, McClain 1978) as shown in Table 3-3. Ice concentrations (or percentages of ice coverage) are estimated on the appearance of the gray-shades while individual ice features such as ice floes, ice edge, and leads are perceptible within the capability of the sensor's resolution. Enhancements of the infrared imagery which entail the assignment of specified temperatures to levels of gray shading facilitates the detection of ice types, particularly the youngest ice forms and the ice-open water boundary by surface temperature differences (Hufford 1981, Jayaweera 1976). Pack ice motion processes are determined through comparison of consecutive observations of lead and polynya formation and closing. Techniques are also available for the automated determination of ice motion vectors using two-dimensional correlation analyses on consecutive images. The presence of melting ice is indicated by subtle changes in the gray tones or texture.of the the imagery.

Table 3-4 shows the NOAA system's compliance to the operational requirements. The NOAA system fulfills all requirements except it does not satisfy the requirement for all-weather observational capability. It was shown, during the Marginal Ice Zone Experiment in the Bering Sea, that the ice edge derived from the NOAA imagery was in close agreement with ground observations (Cavalieri et al. 1983, Cavalieri and Gloersen 1983). The lack of a geographically rectified base map, however, can lead to some errors in the mapping of ice conditions.

Land Satellites (Landsat) - Landsat platforms 4 and 5 are in near polar, sun synchronous orbit but at a lower altitude than the TIROS-N series. The primary earth-observing instruments on these spacecraft are the Multi-spectral Scanner (MSS) and the Thematic Mapper (TM). Both the MSS and TM scan the earth at swath widths of

TABLE 3-4

COMPLIANCE OF THE TIROS-N POLAR ENVIRONMENTAL SATELLITE SYSTEM TO THE OPERATIONAL CRITERIA FOR A FEASIBLE ICE MONITORING SYSTEM

Feature	Requirements	System Compliance Yes	System Compliance No
Ice Concentration	0% - 100%	X	
Ice Edge	Location (1 km)	X	
Ice Thickness/Age	$\leq$ 5 cm, grease	X	
Observing Frequency (must allow for adequate lead time for "Alert")	Once/day	X	
Environmental Operating Capabilities	All-weather/ day and night	 x (AVHRR IR)	x
Reporting Time	Within 3 hr after observation	x	

185 km. The resolutions of the MSS and TM sensors are 80 and 30 meters, respectively. Thematic Mapper data are not taken over the Bering Sea due to the position of the Tracking and Data Relay Satellite (TDRES). A second TDRES was lost in the Challenger space shuttle disaster, thus TM data will not be taken for the Bering Sea in the near future.

Landsat imagery (MSS data only) is processed at the Landsat Quick Look Facility at the University of Alaska in Fairbanks. Hard copy prints of the images are dispersed to the users via air courier express. The time between data receipt and delivery to the users is about 5 hours.

The high resolution capability of the MSS sensor in combination with the high reflectance of ice in all of the MSS spectral bands allows the detection of numerous features of the sea ice cover (McNutt 1981, Campbell et al. 1975, Stringer et al. 1980) as shown in Table 3-3. The MSS visible range is useful for mapping ice concentrations, ice edge, and qualitatively distinguishing thin ice from thicker ice. Lead patterns and ice floe distributions are easily identified by virtue of high contrast linear features (Campbell et al. 1975). Melt features are revealed through low reflectance level in the near-IR range. While individual ice features such as ridges, hummocks and rafted ice are not distinguishable on the Landsat imagery, major ridge systems (40 m wide by 10 km long) are reliably identified (Stringer et al. 1980).

Operational use of the Landsat imagery for ice detection in the Bering Sea is limited-by cloud cover and spatial and temporal coverage. According to Dr. Miller (pers. comm.) of the Quick Look Facility in Fairbanks, the Landsat system provides observation of some part of the Navarin Basin for 7 days in a row every 9 days. Dense cloud cover precludes ice observation; however, "significant" ice detail can be obtained through thin clouds (Stringer et al. 1980).

As Table 3-5 shows, the Landsat system does not satisfy all of the operational criteria established for Navarin Basin ice detection system. The imagery has sufficient resolution to identify those ice conditions associated with bowhead whales, but the routine use of Landsat imagery is hampered by cloud cover and limited areal and temporal coverage of observation over a specific area. The time between observation and delivery of the information to the operators and MMS personnel exceeds, by 2 hours, the minimum time requirements.

TABLE 3-5

COMPLIANCE OF THE LANDSAT SATELLITE SYSTEM TO OPERATIONAL CRITERIA ESTABLISHED FOR A FEASIBLE ICE MONITORING SYSTEM

Feature	Requirements	System Compliance Yes	No
Ice Concentration	0% - 100%	X	
Ice Edge	Location (1 km)	X	
Ice Thickness/Age	≤ 5 cm, grease	X	
Observing Frequency (must allow for adequate "Alert" lead time)	Once/day		X
Environmental Operating Capabilities	All-weather/ day and night		X X
Reporting Time	Within 3 hr after observation		X[a]

a/ Quick Look Landsat imagery available from the University of Alaska 4 to 5 hours after data receipt.

Nimbus 7 - The Nimbus 7 satellite has a passive microwave sensor called the Scanning Multichannel Microwave Radiometer (SMMR). The highest frequency channel (37 Ghz) is processed to 25 km resolution. Algorithms have been developed to provide contours of first year sea ice concentrations in percent which have agreed well with ground truthing in the Marginal Ice Zone experiments (Cavalieri et al. 1983, Cavalieri and Gloersen 1983). In addition, the .81 CM polarization was able to distinguish between new, young and first year ice types (Johnson et al. 1985).

Though the Nimbus 7 satellite continues to be active, the SMMR data are no longer available to the marine community due to budget restraints within NOAA. We have, however, provided information on the application of SMMR data to ice detection since there is a possibility that SMMR data will be available in the future.

Additionally, experience acquired by the ice research community in using SMMR data for ice detection will be the basis for evaluating the potential capability of future satellite systems which will carry instrumentation similar in the SMMR capabilities.

Table 3-3 identifies those ice characteristics that have been obtained from the SMMR by algorithmic extraction, Quantitative fractions (in increments of 10%) of first year (and multi-year) ice are provided by algorithms developed by Swift (1984) and private sector entities. Though field experiments have shown the sensor to have some capability in discerning young ice forms, more research is required to relate microwave emission to the actual aging of sea ice (Swift 1984).

Table 3-6 shows the compliance of the Nimbus 7 passive microwave system to the operational requirements. The coarse resolution of the system precludes fulfilling the ice edge detection requirement of 1 km, and limits the interpretation of ice concentration values of the pack ice. The system does meet the environmental operations capabilities, but the actual operation and reporting traits can not be determined until the SMMR data dissemination is resumed.

Geosat - The U.S. Navy's GEOSAT, launched in March 1985, is a polar orbiting satellite carrying a radar altimeter. The precision is about twice that of the SEASAT-A altimeter (Sherman 1985). Experience with the SEASAT-A and GEOS-3 satellites show that altimetry accurately determined the position of the sea ice boundary without weather and illumination limitations (Dwyer and Godin 1980). In principle, further analysis of the return pulse

TABLE 3-6

COMPLIANCE[a/] OF NIMBUS 7 SATELLITE SYSTEM TO OPERATIONAL CRITERIA ESTABLISHED FOR A FEASIBLE ICE MONITORING SYSTEM

Feature	Requirements	System Compliance Yes	No
Ice Concentration	0% - 100%	X	
Ice Edge	Location (1 km)		X
Ice Thickness/Age	≤ 5 cm, grease	Possible	
Observing Frequency (must allow for adequate "Ice Alert" lead time)	Once/day		X
Environmental Operating Capabilities	All-weather/ day and night	X X	
Reporting Time	Within 3 hr after observation		X

a/ Compliance based on previous experience of the use of SMMR data for" Marginal Ice Zone" field studies (SMMR data not currently available for operational use).

shape can give information on ice characteristics of the inner pack ice (JOI Report, 1985). The sea ice boundary is detected with an accuracy of +/- 8 km (Sherman 1985).

A readout of the GEOSAT digital data occurs at John Hopkins University with further dissemination to the Naval Research Facility at Bay, St. Louis, MS and then to the Fleet Numerical Oceanographic Center (FNOC) at Monterey, CA. The radar altimetry data are presently not available to the marine community, although the techniques for operational use are under development. Also, GEOSAT is presently undergoing an orbital revision, after which it will repeat orbits every 17 days (instead of once per day).

Table 3-3 shows the capabilities of the Geosat for detecting characteristics of the sea ice cover. Currently, the only information expected from radar altimetry is the location of the ice-open water boundary. Previous studies have gathered some qualitative information on lower ice concentrations and very rough information on higher ice concentrations (Dwyer and Godin 1980). However, it is difficult to predict what kinds of information may evolve from future research of radar altimetry.

Table 3-7 shows the compliance of the Geosat system to the operational criteria. It is clear that this system will not supply all of the information necessary to monitor the presence of bowhead whales with regards to specific ice edge characteristics. Because of the narrow field-of-view of the radar altimeter, it is unlikely that daily coverage of the entire Navarin Basin will be obtained. However, the turnaround time for accessing the processed altimeter data will be within three hours according to Wilkerson (pers. comm.) of NOAA.

TABLE 3-7
COMPLIANCE OF GEOSAT SATELLITE SYSTEM TO OPERATIONAL CRITERIA ESTABLISHED FOR A FEASIBLE ICE MONITORING SYSTEM

Feature	Requirements	System Compliance Yes	No
Ice Concentration	0Δ - 100A		X
Ice Edge	Location (1 km)		X
Ice Thickness/Age	≤ 5 cm, grease		X
Observing Frequency (must allow for adequate "Ice Alert" lead time)	Once/day		X (To be revised to once/ 17 days
Environmental Operating Capabilities	All-weather/ day and night	X X	
Reporting Time	Within 3 hr after observation	X	

Airborne Radar Ice Surveillance Technique:

Visual Reconnaissance - Aerial ice surveillance using visual ice observing techniques has benefited the marine ferrying of cargo though icy waters of both civilian and defense establishments along Alaska's Beaufort Sea course. However, visual observation of ice conditions is limited by weather conditions (low ceilings, fog and precipitation) and by darkness. There may be times when good weather conditions and the urgent need for ice information coincide to require visual ice reconnaissance. It is the most effective and inexpensive method of obtaining real-time ice information (this implies the use of a rig-based helicopter in lieu of charter aircraft from the operating area).

Table 3-8 shows the compliance of visual ice observing techniques to the established operational criteria. The shortcomings of this method are associated with clouds and darkness obscuring visibility of the sea ice.

Side Looking Radars (SLR) - Side looking radars are active microwave imaging radars that include both real and synthetic aperture radars. The principal difference between real and synthetic aperture radars is resolution (Inkster 1984) which is independent of aircraft altitude. The resolution (30-40 meters) of the real aperture radar, or Side Looking Airborne Radar (SLAR) is restricted by the length of the antenna that receives the radar signal. The synthetic aperture radars provide higher resolution (6-12 meters) by using the motion of the aircraft to simulate a larger antenna. Both systems display similar capabilities in detecting various sea ice features as shown in Table 3-9 (Lynden et al. 1984, Luther et al. 1984, Grittner et al. 1983, Hengeveld 1978, Loshchilov et al. 1978, McNutt 1977). The lower resolution of the SLAR is the only major difference between the two systems.

TABLE 3-8

COMPLIANCE OF VISUAL ICE RECONNAISSANCE TECHNIQUES TO OPERATIONAL CRITERIA ESTABLISHED FOR A FEASIBLE ICE MONITORING SYSTEM

Feature	Requirements	System Compliance Yes	System Compliance No
Ice Concentration	0% - 100%	X	
Ice Edge	Location (1 km)	X	
Ice Thickness/Age	≤ 5 cm, grease	X	
Observing Frequency (must allow for adequate "Ice Alert" lead time)	Once/day	X	
Environmental Operating Capabilities	All-weather/ day and night		X X
Reporting Time	within 3 hr after observation	X	

The SAR or SLR ice imagery can be telemetered to the user via a VHF radio link when the aircraft is within a 330 km range. The user receives a "snap-shot-like" view of the ice conditions (Lowry 1985).

This information can be real-time imagery or imagery recorded earlier and stored on magnetic tape. This type of data conveyance requires the-user to have, at least, a system capable of reproducing the radar image. The other method of delivering the ice information is by telecopying the analysis to the user after the aircraft has returned to the base of operations. This method is practiced in the Alaska area, however, the time required for performing the reconnaissance over the Navarin Basin, returning to the base of operations and preparing the ice analysis would exceed three hours.

TABLE 3-9
CAPABILITIES OF AIRBORNE RADAR TECHNIQUES IN
DETECTING CHARACTERISTICS OF THE SEA ICE COVER
(Side Looking, Synthetic Aperture and Pulse Compression Radar)

Ice Characteristics	SLR	SAR	PC Radar	Comments
Ice Concentration:	X	X	X a/	
Open Water (10%)	X	X	X	
Very Open Pack (10-30%)	X	X	X a/	
Open Pack (40-60%)	X	X	X a/	
Close Pack (70-80%)	X	X	X a/	
Very Close Pack (90% 100%)	X	X	X a/	
Compact Pact (100%)	X	X	X a/	
Ice Thickness Inferred by Age:				
New Ice	X	X		
Frazil (5cm)				
Grease (5cm)				
Slush (5cm)	X	X		
Shugu (5cm)		X		
Dark Nilas (5cm)	X	X		
Light Nilas (5-10cm)				
Ice Rind (5cm)				
Pancake (10cm)		X		
Young Ice	X	X		
Gray (10-15cm)				
Gray-white (15-30cm)				
First Year Ice (30-120cm)	X	X		
Thin First Year (30-50cm)				
Medium First Year (70-120cm)	X			
Thick First Year (120cm)	X			
Forms of Floating Ice (Diameter):				
Pancake (3m)		X		
Brash (2m)	X b/	X	X b/c/	
Ice Cake (20m)	X	X	X c/	
Small Floe (20-100m)	X	X	X c/	
Medium Floe (100-500m)	X	X	X c/	
Big Floe (500m-2km)	X	X	X c/	
Vast Floe (2-10km)	X	X	X c/	
Giant Floe (10km)	X	X	X c/	
Ice Edge:				
Compacted	X	X	X	
Diffuse	X	X	X	
Ice limit	X	X	X	

TABLE 3-9 (Continued)
CAPABILITIES OF AIRBORNE RADAR TECHNIQUES IN
DETECTING CHARACTERISTICS OF THE SEA ICE COVER
(Side Looking, Synthetic Aperture and Pulse Compression Radar)

Ice Characteristics	SLR	SAR	PC Radar	Comments
Pack Ice Deformation:				
Finger Rafting				
Rafting	X	X		
Ridging	X	X		
Fracturing	X	X		
Hummocking	X d/	X d/		
Pack Ice Motion Processes:	X	X		detected by
Shearing	X	X		sequential
Compacting	X	X		observations
Diverging	X	X		observations
Ice Surface Features:			X	
Level Ice	X	X		
Rafted Ice	X	X		infer by ice type
Ridged Ice	X	X		
New Ridge	X	X		
Weathered Ridge	X	X		
Very Weathered Ridge				
Aged Ridge				
Consolidated Ridge				
State of Melting:				
Puddled	X	X		
Thaw Holes	X	X		
Dried Ice				
Rotten Ice	X	X		
Flooded Ice				
Openings in the Ice:				
Polynyas	X	X	X	
Fracture	X	X		
Fracture Zone	X e/	X		
Leads	X	X	X	

a/ Recognizable under special conditions.
b/ Classified indirectly by pattern recognition.
c/ Recognition requires confirmation by other methods.
d/ Inferred through other features.
e/ Inferred through the presence of fracture in ice.

TABLE 3-10

COMPLIANCE OF AIRBORNE SLAR/SLR SYSTEMS TO OPERATIONAL CRITERIA ESTABLISHED FOR A FEASIBLE ICE MONITORING SYSTEM

Feature	Requirements	System Compliance Yes	No
Ice Concentration	0% - 100%	X	
Ice Edge	Location (1 km)	X	
Ice Thickness/Age	≤ 5 cm, grease	X	
Observing Frequency (Must allow for adequate "Alert" state)	Once/day	X	
Environmental Operating Capabilities	All-weather/ day and night	X X	
Reporting Time	Within 3 hr after observation	Possible a/	

a/ Timelines of delivery of ice information to users dependent on factors associated with scale of mission, location of operations' base, and data downlinking capabilities.

Table 3-10 shows the compliance of the airborne SAR/SLR systems to the operational criteria. Both systems comply with all of the operational criteria. As discussed above, the one possible problem may be the physical limitations in delivery of the ice information to industry and MMS officials in Anchorage within the three hour time limit (based on previous experience, a four to five hour time period is more likely).

Pulse Compression Maritime Patrol Radar - The Pulse Compression (PC) Radar is an upgrade to standard marine search radar in terms of better resolution and sea clutter suppression. The airborne Pulse Compression Radar is considered a potential ice monitoring observation system for the Bering Sea because of field testing conducted over the ice fields off of Newfoundland, Canada. The primary objective of the field tests was to determine the. capabilities of the radar (AN/APS-128) in detecting icebergs which were occasionally embedded in the pack ice (Eaton Corporation 1984, 1985, Currie and Haykin 1985). The field tests showed that the radar was capable of detecting ice targets with a radar cross section of 0.1 to 0.5 square meters at ranges of 40 km. The ice pack could be distinguished from sea clutter using scan to scan integration and "slow decay" techniques. Pack ice was shown as a speckled area and the density of speckles may be related to ice concentration. The radar also showed some ability to provide a gray-scale map of the interior of the pack ice.

Table 3-9 shows the potential capability of PC radar for detecting various sea ice characteristics based on the qualitative evidence gained from the field test program discussed above. No field studies have been conducted to quantitatively relate return echo of PC radar to sea ice characteristics (Inkster-Inters Technologies, pers. comm.). As the table shows, the PC radar is capable of detecting the ice water boundary (ice edge) and the pack ice. This capability is diminished during certain atmospheric conditions.

Table 3-11 shows the compliance of the PC airborne radar system to the operational criteria. While the system fulfills over half of the operational criteria, it cannot be operated during heavy fog or severe weather conditions and the products can not be quantified. Without extensive field testing, it is not possible to determine the capability of the radar to quantify source concentrations. The primary capability of the system would be detecting the ice edge.

Ship-, Land- and Rig-based Radar:

The use of rig-based radar for sea ice monitoring is currently used by several oil companies in both the Canadian and Alaskan sectors (Inters, LTD, pers. comm.) of the Beaufort Sea. Land-based radar systems have been used by the Japanese to study ice movements off the Okhotsk Sea coast of Hokkaido (Tabata 1975, Sonu and Aota 1985). Sea ice movements

TABLE 3-11

COMPLIANCE OF PULSE COMPRESSION MARINE SEARCH AIRBORNE RADAR TO OPERATIONAL CRITERIA FOR A FEASIBLE ICE MONITORING SYSTEM

Feature	Requirements	System Compliance Yes	System Compliance No
Ice Concentration	0%-100%	Possible[a/]	
Ice Edge	Location (1 km)	X	
Ice Thickness/Age	$\leq$ 5 cm, grease		X
Observing Frequency (Must allow for adequate "Alert" state)	Once/day	X	
Environmental Operating Capabilities	All-weather/ day and night	X	X[b/]
Reporting Time	Within 3 hr after observation	X	

a/ Only if targets on the radar screen are defined as specific concentrations through other observational means.

b/ Requirement for low altitude flight limits aircraft operations to "safe" weather conditions while ice detection can be constrained by sea clutter and some meteorological conditions.

through the Bering Strait have been monitored using land-based radar at Tin City, Alaska. Land-based radars are mentioned since partial observation of ice conditions in the Navarin Basin could be accomplished through installment of a radar on Hall Island (northwest of St. Matthew Island). Since these islands are environmentally protected areas, the feasibility of such an' installation is low. A review of the available literature reveals that the fundamental advantage of these systems is the capability of real-time ice observation and the tracking of individual ice features. Shortcomings include range limitations and signal distortion by environmental factors.

Rig-based radars are currently used in conjunction with airborne and other techniques to improve the range at which low lying ice floes can be detected. The radar is, generally, a standard marine search radar mounted on top of a derrick. Canadian Marine Drilling Ltd. uses a derrick-top radar in combination with a standard "bridge top" radar. With the use of a digital radar processor, the scans are integrated to yield more efficient detection and floe velocity information. Targets are typically detected within about 20 kilometers.

The literature surveyed does not provide information on the use of ship-based radar for sea ice detection. It is assumed that this system would have a configuration similar to the radar equipment used on the stable rig platforms and, therefore, have similar system characteristics and operational constraints (discussed below). The obvious advantage of ship-based radar is that the ship can move to within detection range of the ice edge and survey the ice margin along a more or less continuous line.

The capability of sea ice detection by marine radar is affected by atmospheric and oceanographic conditions (Straw, Furuno USA, pers. comm.). The moisture content and temperature of the sea ice and the presence of rain or fog may attenuate the radar signal. High ocean waves are often better detected than sea ice due to their high aspect angle to the radar waves {otherwise known as "sea clutter"). These disruptive environmental conditions are more likely to occur in the Bering Sea than in the Beaufort Sea where the application of rig-based radars for specialized ice detection have been successfully used in this much different environment.

Radar installed on mountain tops by Japanese researchers has been used to detail the behavior of ice floe movements. Features such as polynyas, very high pressure ridges, and ice-open water boundaries were identified as well. Other than the ability to increase the radar horizon (a function of antenna height), land-based radars operate no differently from rig-based radars and hence, are subject to similar constraints in ice detection. Considering the concept of installing radar on Hall Island, the radar range would be on the order of 90 km (assuming the radar was installed at highest elevation of 507 meters). The radar could be remotely controlled by a VHF radio signal and the information transmitted to the rigs by a radar relay system.

The capability of marine radar to define various ice cover characteristics is unclear. The literature reviewed does not reveal the quantitative relationship of radar echo to ice floe sizes or ice concentration. However, ridges and leads are detectable out to a 12 km range using a Radar Image Display System and the ice-open water boundary is discernible when sea clutter is minimized by off-ice winds or when the clutter can be averaged out by filtering techniques (Routledge, pers. comm.). Since, by definition, radar reflectivity depends upon the size, shape, aspect and dielectric properties at the surface of the target (Glossary of Meteorology 1959), studies have been undertaken to quantify the relationship between ice features and radar return. However, these studies are not available in the published literature. Table 3-12 provides what little information is available on the capabilities of rig-based radar in detecting various sea ice characteristics.

The success of ice detection by marine radar seems to be related to the experience of the operator in conventional target plotting techniques and recognition of targets over an extended time period. The targets to be monitored are initially identified by visual or aerial radar observation and then tracked by rig-based radar.

TABLE 3-12
CAPABILITIES OF RIG- OR SHIP-BASED RADAR IN DETECTING CHARACTERISTICS OF THE SEA ICE COVER

Ice Conditions	Rig- or Ship-Based Radar	Comments
Ice Concentration:	X "	possible, requires further research
Open Water (1U%)		
Very Open Pack (10-30%)		
Open Pack (40-60%)		
Close Pack (70-80%)		
Very Close Pack (90%-10U%)		
Compact Pack (100%)		
Ice Thickness Inferred by Age:		
New Ice		
Frazil (5cm)		
Grease (5cm)		
Slush (5cm)		
Shugu (5cm)		
Dark Nilas (5cm)		
Light Nilas (5-10cm)		
Ice Rind (5cm)		
Pancake (10cm)		
Young Ice		
Gray (10-15cm)		
Gray-White (15-30cm)		
First Year Ice (30-120cm)		
Thin First Year (30-50cm)		
Medium First Year (70-120cm)		
Thick First Year (120cm)		
Forms of Floating Ice (Diameter):	X	possible if targets can be identified as specific floes from other sources
Pancake (3m)		
Brash (2m)		
Ice Cake (20m)		
Small Floe (20-100m)		
Medium Floe (100-500m)		
Big Floe (500m-2km)		
Vast Floe (2-10km)		
Giant Floe (10km)		
Ice Edge:	X	
Compacted	X	
Diffuse	X	
Ice limit	X	

TABLE 3-12 (Continued)
CAPABILITIES OF RIG- OR SHIP-BASED RADAR IN
DETECTING CHARACTERISTICS OF THE SEA ICE COVER

Ice Conditions	Rig- or Ship-Based Radar	Comments
Pack Ice Deformation:		
Finger Rafting		
Rafting		
Ridging		
Fracturing		
Hummocking		
Pack Ice Motion Processes:	X	inferred by tracking
Shearing		
Compacting		
Diverging		
Ice Surface Features:	X	inferred by nature of
Level Ice	X	signal return
Rafted Ice		
Ridged Ice	X	
New Ridge		
Weathered Ridge		
Very Weathered Ridge		
Aged Ridge		
Consolidated Ridge		
State, of Melting:		
Puddled		
Thaw Holes		
Dried Ice		
Rotten Ice		
Flooded Ice		
Openings in the Ice:	X	
Polynyas	X	
Fracture		
Fracture Zone		
Leads	X	

Table 3-13 shows the compliance of the rig-, ship- or shore-based radar system to the operational criteria. The discrimination of ice concentration may possibly be facilitated by some radar image processing techniques based on correlations between radar echo and target properties that have been determined by private industry. Given current knowledge, identification of ice features is possible only through comparison of the radar image with "snapshots" of the actual ice conditions taken by either visual or airborne radar reconnaissance. Since the rig-based radar horizon is on the order of 20 km, this is far less than the 220 km radius required for advanced warning of ice incursion.

3.1.3.2 Examination of Ice Observation Techniques (Future Capabilities)

Satellites:

Special Sensor Microwave Imager (SSM/I) - The SSM/I is a passive microwave radiometer that detects thermal energy emitted by the earth-atmosphere system in the microwave portion of the electromagnetic spectrum which is unconstrained by light quality or meteorological conditions. The resolution of the sensor is 25 km. It will be capable of determining the positions of the ice edge within ± 12.5 km and the sea ice cover within ± 12 percent (JOI Report 1985, Sherman 1985). The potential capability of the SSM/I to detect sea ice characteristics is given in Table 3-14. These determinations are tentative, depending on the resolving power of the sensor.

One proposed satellite system will be configured with the SSM/I sensor within the decade. A SSM/I will be installed on the satellite for the Defense Meteorological Satellite Program (DMSP) and launched in 1987. Almost total coverage of the polar regions will be obtained every 24 hours {Sherman 1985).

TABLE 3-13

COMPLIANCE OF SHIP-, LAND-, AND RIG-BASED RADAR SYSTEMS TO OPERATIONAL CRITERIA FOR A FEASIBLE ICE MONITORING SYSTEM

Feature	Requirements	System Compliance Yes	No
Ice Concentration	0%-100%	Possible[a]	
Ice Edge	Location (1 km)	x	
Ice Thickness/Age	≤ 5 cm, grease		x
Observing Frequency (Must allow for adequate "Alert" state)	Once/day	x[b]	
Environmental Operating Capabilities	All-weather/ day and night	x	x[c]
Reporting Time	Within 3 hr after observation	x	

a/ Only possible if targets can be identified as specific ice features by other observational means.

b/ Applies to ship-based radar only. Rig-based radar ice detection limited by radar horizon, therefore, lead time signaling an ice warning would be insufficient.

c/ Ice detection limited by some environmental conditions.

Installation began on an interconnecting link among the Fleet Numerical Oceanographic Center (FNOC), Air Force Global Weather Central (AFGWC) and NOAA's facilities in Suitland, MD in 1985. All centers will exchange their products via a domestic communications satellite link called the Shared Processing System, NOAA will provide Level 11 data which are time-tagged, earth-located, geophysical units. This digital data will be available to the community through the National Weather Service. The SSM/I data may

TABLE 3-14
CAPABILITIES OF FUTURE SATELLITE SYSTEMS IN DETECTING
CHARACTERISTICS OF THE BERING SEA ICE COVER

Ice Characteristics	DMSP (SSM/I)	ERS 1 RADARSAT JERS 1 (SAR)	Comments
Ice Concentration:			
Open Water (10%)	X	X	
Very Open Pack (10-30%)	X	X	
Open Pack (40-60%)	X	X	
Close Pack (70-80%)	X	X	
Very Close Pack (90% 100%)	X	X	
Compact Pack (100%)	X	X	
Ice Thickness Inferred by Age:		X a/	
New Ice		X	
Frazil (5cm)			
Grease (5cm)		X	
Slush (5cm)		X	under certain conditions
Shugu (5cm)		X	under certain conditions
Dark Nilas(5cm)		X	
Light Nilas (5-10cm)			
Ice Rind (5cm)			
Pancake (10cm)		X	
Young Ice		X	
Gray (10-15cm)			
Gray-White (15-30cm)			
First Year Ice (30-120cm)	X	X	
Thin First Year (30-50cm)			
Medium First Year (70-1 20cm)			
Thick First Year (120cm)			
Forms of Floating Ice (Diameter):			
Pancake (3m)		X	under certain conditions
Brash (2m)		X	under certain conditions
Ice Cake (20m)		X	under certain conditions
Small Floe (20-100m)		X	
Medium Floe (100-500m)		X	
Big Floe (500m-2km)		X	
Vast Floe (2-10km)		X	
Giant Floe (10km)		X	
Ice Edge:		X	
Compacted		X	
Diffuse		X	
Ice limit		X	if compacted

a/ Recognition is strongly dependent on season and function of radar system parameters

TABLE 3-14 (Continued)

CAPABILITIES OF FUTURE SATELLITE SYSTEMS IN DETECTING CHARACTERISTICS OF THE BERING SEA ICE COVER

Ice Characteristics	DMSP (SSM/I)	ERS 1 RADARSAT JERS 1 (SAR)	Comments
Pack Ice Deformation:			
Finger Rafting			
Rafting		X	
Ridging		X	
Fracturing			
Hummocking			
Pack Ice Motion Processes:		X	infer through other features
Shearing		X	
Compacting		X	
Diverging		X	
Ice Surface Features:			
Level Ice		X	
Rafted Ice		X	
Ridged Ice		X	
New Ridge		X	
Weathered Ridge		X	
Very Weathered Ridge			
Aged Ridge			
Consolidated Ridge			
State of Melting:			
Puddled		X	
Thaw Holes			
Dried Ice			
Rotten Ice			
Flooded Ice			
Openings in the Ice:			
Polynyas	X	X	resolution limited for DMSP
Fracture		X	
Fracture Zone		X	
Leads		X	

also be distributed through the Naval Ocean Data Distribution System. The users may also obtain the satellite data directly from a Local User Terminal (LUT).

Whatever the method of data retrieval, algorithms (computer software) will need to be developed by industry to translate the digital data into a form showing ice edge location and ice concentrations. Algorithms are presently under development to make the ice information routinely available for meteorologists at AFGWC and the Navy's FNOC to support ship routing in the polar regions (U.S. Air Force). Presumably, the data will also be available to the Joint Navy/NOAA Ice Center in Suitland, MD for inclusion on their ice maps transmitted to Alaska three times weekly on National Weather Service circuits.

The compliance of the DMSP satellite system to the MMS stipulated operational requirements is given in Table 3-15. This system should be capable of identifying ice concentrations and the sea ice edge but the resolution will be low. As already mentioned (Section 3.1.3), the Marginal Ice Zone Experiments in both the eastern and western Arctic showed that the passive microwave data from the Nimbus 7 SMMR observation of the ice edge and ice concentrations coincided to a high degree with ground-truth measurements by aircraft. It is expected the SSM/I sensor will perform equally as well.

According to the available literature, there are no algorithms under development to extract ice types (ice thickness inferred) from the SSM/I sensor data other than discriminating between first year and multi-year sea ice. Such a requirement may be pursued by private interests that receive the sensor data directly from the satellite on a Local User Terminal. The timeliness of receiving the data in a form useful for monitoring purposes depends on the design of the Shared Processing System and the extent to which NOAA participates.

TABLE 3-15

COMPLIANCE OF DMSP SATELLITE PROGRAMS TO OPERATIONAL CRITERIA FOR A FEASIBLE ICE MONITORING SYSTEM

Feature	Requirements	System Compliance Yes	No
Ice Concentration	0%- 100%	X a/	
Ice Edge	Location (1 km)		X
Ice Thickness/Age	< 5 cm, grease		X
Observing Frequency (Must allow for adequate "Alert" state)	Once/day	X	
Environmental Operating Capabilities	All-weather/ 'day and night	X X	
Reporting Time	Within 3 hr after observation	Possible	

a/ To the nearest 10 percent only.

Synthetic Aperture Radar (SAR) - The Synthetic Aperture Radar is an active microwave radar which electronically synthesizes the equivalent of an antennae large enough to achieve a spatial resolution of a few tens of meters (Weeks and Baker 1985). The usefulness of SAR in detecting most sea ice characteristics unobstructed by weather or darkness was proven by the Seasat-A satellite launched in 1978 (now defunct) and by numerous SAR aircraft overflights.

Three satellites containing SAR systems are scheduled for future deployment:

1. ESA (European Space Agency) Remote Sensing Satellite #1 (BRS1) launch: 1989
2. Canada's Radar Satellite (Radarsat): 1990
3. Japan's Earth Resources Satellite #1 (J-ERS-1): 1990

The SAR sensor capabilities for determining various sea ice cover parameters (Weller et al. 1983, Jet Propulsion Laboratory 1978) are shown in Table 3-14. It is clear that these satellite systems will provide detailed information on the character of the ice margin for all-weather, day and night conditions.

A SAR readout station will be established at the Geophysical Institute at the University. of Alaska. in Fairbanks in 1988 (Weller et al. 1983). This station will receive a few minutes of SAR data daily from both the ERS1 and Radarsat satellites and possibly the Japanese SAR satellite when they become operational in 1989 to 1991. Current plans are to have a digital representation of ice image made within 3 to 5 hours after the raw SAR data are downlinked (Miller, pers. comm.). The digital image will be available at the readout facility and relayed to NOAA/Navy Joint Ice Center in Suitland, Maryland and to NOAA's ocean service Anchorage facilities. The automated extraction of ice types and concentration will depend upon the development of algorithms by either research groups or industry.

Table 3-16 estimates the compliance of the future satellite SAR systems to the operational criteria. Experience with the Seasat-A SAR and aircraft-borne SAR show that the sensors will likely be capable of detecting those ice features found associated with bowhead whales. The main drawback of the SAR imagery for monitoring planning purposes is the temporal and spatial limitations of coverage. Since minimum swath widths for ERS-1 and Radarsat ice surveillance will be 80 and 130 km, respectively, it

TABLE 3-16

COMPLIANCE OF SATELLITE SAR SYSTEMS TO OPERATIONAL CRITERIA FOR A FEASIBLE ICE MONITORING SYSTEM

Feature	Requirements	System Compliance Yes	No
Ice Concentration	0%-1 00%	X	
Ice Edge	Location (1 km)	X	
Ice Thickness/Age	≤ 5 cm, grease	X	
Observing Frequency (Must allow for adequate "Alert" state)	Once/day	Possible[a/]	
Environmental Operating Capabilities	All-weather/ day and night	X X	
Reporting Time	Within 3 hr after observation	x	

a/ Possible based on optimal program.

is certain that gaps in areal coverage will occur. The determination of orbital configurations and SAR data allotments to participating countries will depend upon research and operational needs to be decided in future negotiations.

Polar Platforms:

NASA's Polar Platform is one of the planned elements of the Space Station Complex which will provide a unique vantage point for monitoring oceanographic processes (McElroy and Schneider 1984). A precise date for deployment is not set and may be significantly delayed due to the space shuttle disaster.

The system will consist of two platforms called Alpha and Beta (collectively known as the Polar Platform). Both platforms will contain a suite of oceanographic monitoring instruments which comprise a part of NASA's "Earth Observing System" (EOS). Both platforms will carry a Coarse Resolution Microwave Imager and a radar altimeter which are similar in ice detection capabilities to the SSM/I on the DMSP and the radar altimeter on the Geosat satellite, respectively. A SAR, based on Seasat and the Shuttle Imaging Radar (SIR) will be carried only on the Alpha Platform and will provide all-weather ice imagery at a ground resolution of 30 meters (McElroy and Schneider 1984, 1985). This SAR, called a SEASAR, will be designed to satisfy both operational and research requirements (Butler 1984).

Considerable attention will be paid to data processing and distribution. Some processing will be done on-board for "quick-look" purposes and direct broadcast. The direct broadcast scheme will be similar to what is practiced now in the dissemination of NOAA satellite imagery. It is speculated that SEASAR imageries of arctic sea ice conditions (including the Bering Sea) will be directly downlinked to the SAR readout station that is to be located in Fairbanks.

The Polar Platform will carry ice sensing instrumentation that has evolved from the missions planned for the 80's (DMSP, Geosat, ERS1, J-ERS1 and Radarsat) as well as from previous satellite systems such as Nimbus 7 and Seasat-A. The capabilities of each of these ice monitoring systems in detecting sea ice and meeting operational requirements has already been discussed. It is apparent that, conceptually, the Polar Platform will provide a comprehensive coverage of sea ice conditions at a frequency sufficient to meet operational requirements.

Buoys :

Three kinds of buoys are considered for ice detection purposes: ice drift buoys, hydroacoustical buoys, and specially designed moored buoys.

Ice Drift Buoys - Ice drift buoys have limited application to this study, since it is difficult to determine from the drift data whether the buoy is on the ice or in the sea (Vinje 1'378). This discrimination may be aided by the installation of a temperature sensor on the bottom of the buoy, but once having entered the water their usefulness for monitoring sea ice diminishes. Though their drift rates may give a good indication of wind velocity and, therefore, are useful for ice forecasting, this factor is only partially relevant to the objectives of this study. In view of these considerations, ice drift buoys are not considered a reliable system for monitoring the Bering Sea ice edge.

Sonobuoys - Hydroacoustical measurements"of the marginal ice zone have included fixed and free drifting sonobuoy arrays (McPhee 1983). Hydroacoustic technology has also been applied to monitoring marine biology (Cummings 1983). Fixed location hydroacoustic techniques have been applied to under-the-ice assessment of fish activity (Ehrenberg 1983). Apparently, acoustical techniques have never been used to operationally monitor the advance of the ice edge in any sea.

The problems associated with applying sonar techniques to operational ice monitoring are formidable (Cummings and Untersteiner, pers. comm.). These problems are related to the physical impact of sea ice on the buoy system, data telemetry, power needs and interpretation of the acoustic signal. Submerged buoys would not be affected by drifting ice; however, the telemetry of the data requires either an acoustic or hardwire link with an RF transmitter on a moored surface buoy which would be vulnerable to drifting sea ice (Ehrenberg 1983). Also, technology needs to be developed that minimizes power consumption, thereby diminishing the need for frequent trips to recharge the batteries. Since the acoustic signal is unique for each material sensed, the task of identifying the signal of various sea ice forms would entail a field program involving the services of the few available experts in acoustical tomography. Ultimately, the interpretive process must be automated for a real-time observation network to be viable. Further research on the application of acoustic or sonar techniques for detecting sea ice is being sought by the U.S Government for Antarctic ice monitoring purposes (Ehrenberg, pers. comm.). A similar field program would be required for the Bering Sea before conclusions can be reached about the feasibility of employing acoustical techniques for ice monitoring.

Table 3-17 estimates the compliance of hydroacoustical ice sensing techniques (moored buoys) to the operational criteria. As the table shows, there is potential for measurement of certain ice parameters with no environmental limitations. However, it is evident that a significant research and development effort must be undertaken to make this system viable.

Submersible Buoys - A moored buoy equipped with an Argos transmitter can be designed to be submerged under the advancing ice pack with the cessation of transmission indicating the presence of ice (McDowell, pers. comm.). A small, deep-moored buoy configured with a salt water switch "duck-under" mounted on top of the antenna can alternatively act to terminate the signal in the presence of a saline solution (Anderson, pers. comm.). Thus, the first sign of encroaching ice is the sporadic (or continuous) loss of signal.

The ARGOS satellite capability provides for monitoring the signal from the buoys at roughly two hour intervals in the Navarin area. The signal is received by the NOAA satellites equipped with the Argos Data Collection and Location System (DCLS) which downlinks the data to one of three existing telemetry ground stations. The data are ultimately processed at the Argos Data Processing Center in Toulouse, France. The data are directly accessed by international Telex or a modem-equipped telephone. Data acquisition-to-availability time averages four hours (ARGOS Users Guide 1984).

TABLE 3-17

COMPLIANCE OF HYDROACOUSTICAL BUOYS TO OPERATIONAL CRITERIA FOR A FEASIBLE ICE MONITORING SYSTEM

Feature	Requirements	System Compliance Yes	No
Ice Concentration	0%-100%	Possible[a/]	
Ice Edge	Location (1 km)	Possible[a/]	
Ice Thickness/Age	$\leq$ 5 cm grease	Possible[a/]	
Observing Frequency (Must allow for adequate "Alert" state)	Once/day	X	
Environmental Operating Capabilities	All-weather/ day and night	X X	
Reporting Time	Within 3 hr after observation	X[b/]	

a/ Possible given further study and field experience.

b/ Direct readout only.

The data can also be transmitted to one of the NOAA satellites (whichever one is in view of the platform) which contain a VHF beacon transmitter that continuously telemeters the data being received. It can be downlinked to a Local User Terminal (LUT) within a 1,200 kilometer view-range of the satellite. The LUT stores all of the data received and when the satellite has passed from view, extracts the pertinent platform data. The number of satellite passes within range of the Navarin Basin is about twelve per day, therefore, monitoring the status of the buoys can be accomplished at least every three hours. Another data communications method involves bouncing the radio signal off of ionized meteor burst trails (Sytsma and Leader 1982). Meteor burst communication allows the telemetering of data up to distances of

2,000 km. Since meteor trails are available every three minutes, the status of the buoys can be determined more frequently than by the system using the NOAA satellites.

Table 3-18 shows the hypothetical capabilities of the "submersible" buoys for detecting various sea ice characteristics. Based on the premise of the system, it is possible that the ice concentrations can be empirically correlated with the frequency of "duck-under" events. Once the ice edge has passed over the location of the buoy, the resumption of the signal and its duration may suggest the presence of leads and polynyas.

Table 3-19 shows the capability of the submersible buoy ice" monitoring technique to meet the operational criteria. The advantage of this technique is its potential reliability in timely signaling of ice incursion within the 220 km radius of the rig site and the subsequent tracking of the ice edge advance at a relatively low cost. The capability of distinguishing various ice concentrations, however, depends upon corroborating the system response to changing ice conditions with ground truthing (satellite and/or airborne observation). This method will have to be used in combination with other observation systems to fulfill the operational criteria since the parameter of ice thickness cannot be determined.

3.1.4 Summary

The evaluation of the ice monitoring systems in terms of satisfying system requirements is summarized in Table 3-20. No current satellite system, or combination thereof, will satisfy all of the operational criteria for an effective ice monitoring system. Both the TIROS/NOAA and the Landsat satellites are unreliable due to cloud limitations, while Nimbus 7 passive microwave satellite is, in addition to its questionable availability, lacking in resolution and rapid data

TABLE 3-18

POTENTIAL CAPABILITIES OF MOORED SUBMERSIBLE BUOYS IN DETECTING CHARACTERISTICS OF THE SEA ICE COVER

Ice Characteristics	Moored Submersible Buoys	Comments
Ice Concentration:	Xa/	
Open Water (10%)	X	
Very Open Pack (10-30%)	Xa/	
Open Pack (40-60%)	Xa/	
Close Pack (70-80%)	Xa/	
Very Close Pack (90% 100%)	Xa/	
Compact Pact (100%)	X	
Ice Thickness Inferred by Age:		
New Ice		
Frazil (5cm)		
Grease (5cm)		
Slush (5cm)		
Shugu (5cm)		
Dark Nilas (5cm)		
Light Nilas (5-10cm)		
Ice Rind (5cm)		
Pancake (10cm)		
Young Ice		
Gray (10-15cm)		
Gray-White (15-30cm)		
First Year Ice (30-120cm)		
Thin First Year (30-50cm)		
Medium First Year (70-120cm)		
Thick First Year (120cm)		
Forms of Floating Ice (Diameter):		
Pancake (3m)		
Brash (2m)		
Ice Cake (20m)		
Small Floe (20-100m)		
Medium Floe (100-500m)		
Big Floe (500m-2km)		
Vast Floe (2-10km)		
Giant Floe (10km)		

TABLE 3-18 (Continued)

POTENTIAL CAPABILITIES OF MOORED SUBMERSIBLE BUOYS IN DETECTING CHARACTERISTICS OF THE SEA ICE COVER

Ice Conditions	Moored Submersible Buoys	Comments
Ice Edge:	X	
Compacted		
Diffuse		
Ice limit		
Pack Ice Deformation:		
Finger Rafting		
Rafting		
Ridging		
Fracturing		
Hummocking		
Pack Ice Motion Processes:		
Shearing		
Compacting		
Diverging		
Ice Surface Features:		
Level Ice		
Rafted Ice		
Ridged Ice		
New Ridge		
Weathered Ridge		
Very Weathered Ridge		
Aged Ridge		
Consolidated Ridge		
State of Melting:		
Puddled		
Thaw Holes		
Dried Ice		
Rotten Ice		
Flooded Ice		
Openings in the 'Ice:	Xa/	
Polynyas	Xa/	
Fracture		
Fracture Zone		
Leads	Xa/	

a/ Possible with futher research.

TABLE 3-19

COMPLIANCE OF SUBMERSIBLE MOORED BUOYS TO OPERATIONAL CRITERIA FOR A FEASIBLE ICE MONITORING SYSTEM

Feature	Requirements	System Compliance Yes	No
Ice Concentration	0%-100%	Possible[a]	
Ice Edge	Location (1 km)	X	
Ice Thickness/Age	$\leq$ 5 cm, grease		X
Observing Frequency (Must allow for adequate "Alert" state)	Once/day	X	
Environmental Operating Capabilities	All-weather/ day and night	X X	
Reporting Time	Within 3 hr after observation	X[b]	

a/ Possible given further study and field experience.

b/ Direct readout only; 3 to 5 hours if using Service Argos.

TABLE 3-20

COMPARATIVE SUMMARY OF THE CAPABILITIES OF CURRENT AND FUTURE ICE MONITORING TECHNIQUES IN MEETING SYSTEM REQUIREMENTS

System	Criteria a/						
	1	2	3	4	5	6	7
A. CURRENT:	Y= Yes, N = ND, P= Possible ( ) = Conditional (see text)						
1. satellites:							
a. NOAA Satellites							
AVHRR Visible	Y	Y	(Y)	Y	N	N	Y
AVHRR Infrared	Y	Y	(Y)	Y	N	Y	Y
b. Landsat (MSS)	Y	Y	(Y)	N	N	N	N
c. Nimbus 7 (SMMR)	Y	N	P	N	Y	Y	N
d. Geosat (altimeter)	N	N	N	N	Y	Y	Y
2. Aerial:							
a. SLR/SLAR	Y	Y	(Y)	Y	Y	Y	P
b. Marine Radar	P	Y	N	Y	N	Y	Y
c. Visual	Y	Y	Y	Y	N	N	Y
3. Rig-, Ship-, Land-Radar	P	Y	N	(Y)	N	Y	Y
B. FUTURE SYSTEMS:							
1. Satellites:							
a. DMSP (1987) (sS4/1)	(Y)	N	N	Y	Y	Y	P
b. SAR Satellites: ERS-1 (1989) Radarsat (1990) J-ERS-1 (1991)	Y	Y	(Y)	P	Y	Y	(Y)
c. Alpha/Beta Polar Platforms (mid-1990's)	Y	Y	(Y)	P	Y	Y	(Y)
2, Point Observation:							
a. Sonobuoys	P	P	P	Y	Y	Y	Y
b. Moored Submersible Buoys	P	Y	N	Y	Y	Y	Y

a/ 1. Ice Concentration: O - 100%.

2. Ice Edge: Distinguish (_1 km) southern margin of pack ice from open ocean.

3. Ice Thickness/Age: Distinguish grease (less than or equal' to cm] trom young or first year ice.

4. Observing Frequency must provide for adequate lead time when ice moves within 220 km radius of rig and advancing at 80 km/day (minimum observing frequency required: once daily).

5. All-Weather Observing Capabilities

6. Day/Night Observing Capabilities

7. Reporting Time: Within 3 hrs after observation.

turnaround. The radar altimeter data from the Geosat (when it comes on line) will be a reliable method of locating the ice-open water boundary during cloudy periods, but only on certain days and in widely scattered areas.

The only existing system for ice detection that will meet all of the requirements is airborne active microwave radar. An aircraft can fly above turbulent weather and image the ice with a high degree of detail independent of weather and light conditions. Sophisticated analog and digital processing algorithms allow real-time data processing and downlinking of the image data to a surface site. However, the practice usually followed in the Alaska area is to analyze the data once the aircraft has returned to the base of operations. This introduces time delays in view of the long ferrying distances to and from the Navarin Basin. Without direct downlinking of the data to a drill site, it is possible only under the most favorable conditions to transmit the analyzed data, or telecopy the hard copy imagery, to the field personnel and MMS officials within three hours after the aircraft overflight.

Aircraft equipped with Pulse Compression (PC) radar, which is a more advanced version of standard Marine Patrol Radar, have a limited capability to detect ice characteristics required to monitor pack ice. Given optimal weather and sea conditions, the PC radar would be capable of detecting an ice-open water boundary and certain features of the ice zone at an average range of 30 to 40 km. Significant wave action at the ice edge or precipitation will depreciate the quality of the radar return. Inclement weather will also affect the aircraft since operating altitudes are low. Though the radar capability is not limited by the lack of light, visual confirmation of radar targets is occasionally necessary and, therefore, difficult during low light conditions.

The advantages and disadvantages of visual ice reconnaissance are fairly obvious. There are occasions, when this approach used in combination with aerial radar overflights proves effective in ground truthing and filling in data needs.

Rig- or ship-based radar is useful for tracking the movement of ice at close range (about 20 km). While a ship may ferry to within detection range of the pack ice, the rig-based radar will be effective only when the ice moves within range; therefore, rig-based radar is inadequate in terms of warning criteria.

A synthesis of satellite and aircraft observations of ice conditions is an optimal approach to satisfying operational requirements. The observations from satellites provide a broad areal coverage of ice conditions and are useful for tracking the ice edge southward through the Bering Sea when it is beyond the 220 km radius from the drillsite. Aerial ice reconnaissance using microwave radar accurately locates the ice edge and distinguishes ice concentrations, and if necessary, ice development stages in the pack ice.

The advent of the SAR ocean sensing satellite missions at the end of the 1980's will undoubtedly enhance the quality of operational ice information and reduce the effect of environmental constraints. Some questions remain to be answered concerning data retrieval and delivery of the information to field personnel in a time frame sufficient for making tactical decisions. Current plans indicate that operations contingent on real-time, all weather ice information will be achieved by the SAR satellite systems and the Polar Platform in the 1990’s.

The microwave sensor on the DMSP satellite, scheduled for implementation in 1987, will permit the detection of ice features but the resolution will be 25 km. With this coarse resolution, only information on ice concentrations (to the nearest 10 percent) can be provided independent of cloud cover and light conditions. Daily coverage of the Navarin Basin area is expected. However, data processing may possibly require more time than is desired for an effective ice warning program. As evidenced from the operational use of similar ice information acquired from the Nimbus 7 satellite, the DMSP ice data will be corroborated with the ice observations from the NOAA system to improve the continuity of ice edge detection.

The use of surface moored buoys which sense the presence of ice either through acoustical means or by physical contact, is a feasible alternative ice monitoring system. Employing hydroacoustical techniques will require substantial field work to develop the system. Moored buoys which submerge beneath the encroaching ice pack provide an alternative means of locating the ice edge and tracking the ice as it moves by certain points. This system satisfies the early warning criteria and requirements for all the environmental characteristics. Since no information is obtained on ice characteristics, a moored buoy program would have to be used in combination with satellite or aircraft ice observation to satisfy all operational requirements.

3.2 COSTS AND OPERATIONS OF MONITORING SYSTEMS

3.2.1 Introduction

This section provides information on the operation costs of the ice monitoring systems and an evaluation of their reliability, facility of use, and attainment of the requirements specified by the Minerals Management Service for an effective sea ice monitoring system. The systems examined include satellite, airborne, and surface platform based ice observation systems.

3.2.2 Methods

Data on the operational costs of sea ice monitoring systems, including the maintenance of the system and the acquisition of data (communication and equipment costs) were obtained from the manufacturers and private sector contractors who supply, or who could develop the capability to supply, these services and with the public utilities which provide data transmission services.

The operational costs of satellite, airborne radar, and surface platform ice monitoring systems are given in Tables 3-21, 3-22, and 3-23, respectively. These costs are expressed as daily costs of equipment operation, data processing or interpretation and, when appropriate, the total cost of equipment acquisition.

TABLE 3-21

COSTS (PER DAY) OF SATELLITE MONITORING SYSTEMS

Satellite	Receiving Equipment	Data Link	Analysis	Expendable	Maintenance	Total
NOAA Series	$15	$1	$20	$2	$3	$41
Landsat	$125	$250 (per surveillance window)	$40	none	none	$165-$290
Geosat[a]	$33	included in receiving equipment		none	none	$33
DMSP[b]	Costs not available.					
ERS-1,2[b]	Costs not available.					
Radarsat[b]	Costs not available.					
JERS-1[b]	Costs not available.					
Polar Platform[b]	Costs not available.					

a/ Geosat radar altimetry data are not currently delivered to the marine community.

b/ Satellites scheduled for future launching.

TABLE 3-22

COSTS OF AERIAL RADAR MONITORING SYSTEMS

Radar System	Development Costs/Receiving/ Downlink Equipment/ Data Processing	Service Contract (Includes Technicians, Data Processing)
Synthetic Aperture Radar (SAR)	$8,000- $10 ,000K	$20K/day + $600 per flight hour
Side Looking Radar (SLAR)	$7,000 - $9,000K	$7 K/day + $900 per flight hour
Marine Patrol Radar	$500-$1 ,000K	Not available.

Note: The service contract rate does not include the necessary equipment at the site to receive the imagery in real-time. The image product is usually analyzed at the base of operations and the analysis can be transmitted to the client via telecopier.

TABLE 3-23

COSTS OF ICE BUOYS AND MOORED MONITORS

Surface Platform System	Cost/Unit	Receiving Equipment (Data Collection/ Position)	Total Service Contract (Equipment and Data Analysis)
Ice Buoys Moored Monitors	$7-9K	$25-$30/day (via Service Argos) $40K (Local User Terminal--purchase price.)	$100/day

Note: The cost per unit includes the cost of a Platform Terminal Transmitter (PTT) but not that required for development of moored monitors.

Information on the systems' reliability, equipment durability, degree of maintenance and facility of their use was largely obtained from the author's personal experience with these systems. Further information on radar ice detection techniques was gleaned from final reports written by NOAA and NASA Principal Investigators. Information on the development and reliability of ice buoys and moored monitors came directly from a manufacturer. This information is summarized in Table 3-24 and discussed in Section 3.2.3. The systems were qualitatively rated and the assigned values were determined from opinions gathered from individuals knowledgeable about the operation of the systems.

3.2.3 Results and Discussion

3.2.3.1 Satellite Monitoring Systems

There are three satellite systems which currently have ice detection capabilities, while at least five are planned in the future (Table 3-21). Routine ice information is obtained from both NOAA and Land satellites while sea ice data from Geosat has not been requested

TABLE 3-24

QUALITATIVE RATINGS FOR VARIOUS ICE MONITORING SYSTEMS[a/]

Ice Monitoring System	Reliability of System: Durability	Reliability of System: Maintenance: Ease	Reliability of System: Maintenance: Freq. (days)	Facility of Use: Access to Information	Facility of Use: Simplicity of Operation	Attainment of System Requirements	Timeliness of Reporting System
Satellite							
Polar Orbital (NOAA 9)	3	3	15	3	3	No	3
Landsat	3	NA	NA	2	2	No	2
Nimbus	3	NA	NA	1	1	No	U
Geosat	3	3	6 mo.	3	3	No	3
DMSP (future)	3	3	6 mo.	3	3	No	U
SAR (future)	3	U	U	u	u	Yes	3
Polar Orbital (future)	3	3	15	3	3	No	3
Airborne Systems							
Side Looking Radar	3	2	U	3	2	Yes	3
Synthetic Aperture	3	2	U	3	2	Yes	3
Marine Patrol Radar	3	3	U	1	3	No	3
Surface Platform Systems							
Sonobuoys	2	1	NA	3	2	No	3
Moored Monitors	u	1	NA	3	2	No	3

a/ Qualitative Rating Categories: 3--Good; 2--Intermediate; l--Poor; NA--Not Applicable; U--Undetermined (because information is not available) by the civil marine community in Alaska. The new generation of ocean sensing satellites carrying passive and active microwave radiometers will provide considerably more information on polar ice conditions than what is currently available. The availability of Synthetic Aperture Radar (SAR) observations of sea ice from satellites and associated costs will be linked to an Alaska SAR Facility (ASF) tnat will be established at the University of Alaska, Fairbanks during 1987-90.

NOAA Polar Orbital Satellites:

Advanced Very High Resolution Radiometers on the NOAA satellites provide visible and infrared images of the sea ice cover. NOAA 9 and 10 imagery are currently received; however, six more in this series will be launched by the year 2000.

Table 3-21 shows the cost associated with accessing the actual NOAA satellite imagery on a daily basis at a particular land site. Tne costs of receiving the actual imagery at a remote offshore site are not considered since it is more practical to transmit the ice condition analysis or a copy of the imagery via telecopier or other facsimile device. The daily costs of the receiving equipment, the data link, and processing are derived from the present lease rate for one UPI Unifax II GOES Satellite Receiver and the service charge for a GOES-TAP on a Satellite Field Service Station (SFSS - a NOAA facility). Not included in this daily cost is a one time connect charge of $1,000. The cost of analyzing the imagery is based on commercial rates in the Alaskan area. Expendable include paper and processing chemicals. Two hours (at $45 per hour) of maintenance per month is standard practice.

Arrangements can be made to obtain copies of the NOAA satellite imagery from the SFSS at tne National Weather Service in Anchorage on a same day basis. Fees may be levied to cover duplication costs, but no pricing program is currently in effect. Analysis of ice conditions derived from NOAA satellite data is prepared three times per week at the NOAA facility and disseminated via the NWS facsimile service. An Alden Facsimile Recorder is needed to receive these data and the cost of equipment and data link exceed that of the UPI satellite receiver.

As shown in Table 3-24, the reliability of this system is good and it is easy to operate. However, the fact that the AVHRR imagery of ice conditions lacks all-weather capability means that it does not meet the system requirements as specified by the MMS.

Land Satellites (Landsat):

Landsat ice condition imagery is obtainable on an operational basis only from the Quick Look Facility operated by the University of Alaska in Fairbanks. Charges are made per surveillance window, which, in the northern latitudes, consists of three adjacent ground tracks (paths) during which the Landsat sensors view a part or all of a target area. The image products include enhancements and enlargements produced on 9-inch film or paper. The image must be manually rectified into geographical coordinates to perform the analysis; thus, accounting for an analysis fee of about two hours per target area at $20 per hour.

Since cloudy conditions limit the usefulness of the Landsat, imagery for ice analysis, imagery should be ordered only when the ice cover is visible. Such determination is facilitated by using the NOAA satellite imagery to discern the cloud conditions in the area of interest. The National Weather Service in Anchorage or Fairbanks can provide this information.

The costs to deliver the images to locations beyond Fairbanks are not included in Table 3-21. Air courier express provides same day service to most cities in Alaska for about $25.

The use of Landsat imagery for ice analysis is considered reliable only when the target area is virtually cloud free. Furthermore, since the three ground tracks which comprise the surveillance window typically occur within a nine day time period, the target area images may be a few days old by the time they are received. Thus, only at rare times can the Landsat imagery be useful in monitoring the ice edge to the degree specified by the MMS.

Geosat:

Radar altimetry data from the U.S. Navy's Geosat are capable of detecting, without environmental restraints, the ice-open water boundary over a small area. According to personnel operating the Naval Ocean Data Distribution System (NODDS), radar altimetry data can be made available in response to any user requests.

The costs developed in Table 3-21 assume that the radar altimetry information is Level II data which shows the ice-open water boundary in time-tagged, earth located geophysical units. The cost of acquiring the radar altimetry data is further based on leasing a computer data link with the NODDS and including a charge per connect-hour and quarterly administration fee (charged by NOAA). Since there has been no prior operational application of these data, it is not known if additional work (implying added costs) is needed to prepare the data for delivery to the user.

Using the computer data link approach offers reliable and simple access to the Geosat ice information as shown in Table 3-24. Since the altimetry data will only indicate an ice-open water boundary with little information on sea ice characteristics, the Geosat does not meet all of the MMS requirements for an ice monitoring system.

DMSP :

The Defense Meteorological Satellite Program (DMSP) will carry a passive microwave radiometer called a Special Sensor Microwave Imager (SSM/I) . The launch of the DMSP satellite is scheduled for 1987.

The Joint NOAA/Navy Ice Center in Suitland, Maryland will probably incorporate the SSM/I information on ice extent and ice cover into its daily ice analysis for the Northern Hemisphere. These ice charts will be facsimile to the National Weather Service Forecast Offices in Alaska which will make them available to the user community. The SSM/I data may also be available on the NODDS. The costs for acquiring the data will probably be on the order of tens of dollars per day.

Access to the information should be convenient and routine. The SSM/I data will, however, like the radar altimetry data, need to be corroborated with other ice information to form a complete ice monitoring program.

Synthetic Aperture Radar (SAR) Satellites:

A new generation of oceanic satellite sensing technology will commence with the launch of the European Space Agency's (ESA) ERS-1 satellite in 1989. The ERS-1 satellite will carry an active microwave sensor called Synthetic Aperture Radar (SAR) which will allow unrestricted observation of detailed features of the sea ice cover. More SAR satellites are planned for launch during the 1990s.

The SAR digital data for the Alaska marine area will be processed at the University of Alaska, Fairbanks. The establishment of this station, called the Alaskan SAR Facility (ASF), is being undertaken by NASA whose primary task is to make the data available to ESA Principal Investigators for research purposes. Planning for the commercial (or operational) use of SAR data, which implies a fast delivery service, comes under the responsibility of NOAA. The acquisition of ERA-1 SAR will be competitive among several investigators and preference will likely be determined by ESA.

Satellite SAR data are not expected to begin to satisfy commercial operational requirements for ice information until the 1990s when information will be processed from more than one orbiting SAR sensor.

The costs to the private sector for obtaining the SAR imagery and the methods by which the data may be passed to other government agencies are unknown.

3.2.3.2 Airborne Systems

Table 3-22 gives the purchase costs and lease rates of three types of aerial radar ice monitoring systems. The purchase costs were obtained from manufacturers and represent a general range of prices; albeit, very sophisticated SAR systems are much more expensive than shown. The lease rates are based on an average of quotes received by two service companies. The overall costs of a leasing program vary depending on whether the aircraft is on standby, engaged in other proximate work, and other negotiable factors.

A Marine Search Radar (Pulse Compression Radar) equipped aircraft is a less costly ice surveillance method than SAR or SLR aircraft, but the radar is incapable of detecting certain ice features that are important in identifying ice conditions associated with bowhead whales. Moreover, the aircraft is vulnerable to turbulent weather conditions due to the low altitudes needed for adequate radar return.

Clearly, the Airborne SAR and SLR ice monitoring systems are highly reliable for obtaining routine ice information in compliance with the MMS operational criteria. Marine Search Radar is adequate for only the detection of the ice boundary and high profile features of the inner ice pack. Rates for the Marine Search Radar system have not been determine since it is still undergoing field tests.

3.2.3.3 Surface Platform Systems

The estimated costs for surface deployed ice buoys and moored monitors are given in Table 3-23. The cost per buoy includes the cost for a Platform Terminal Transmitter which is needed to telemeter the data to the Data Collection System on the NOAA 9 satellite. The data are collected and processed by the Service Argos System which is located in France or by a Local User Terminal (LUT) which receives the signal directly from the satellite (within 2,000 nautical miles). Both Service Argos and the LUT provide printouts of the buoys' position and data collected (temperature, pressure etc.). The buoys' location and data information can be queried from Service Argos via computer data link (Tymnet charges are not included in the daily rate).

The moored monitors consist of hydroacoustical buoys and submersible buoys, both of which require development and field testing. The costs for design, field testing and deployment are not determined.

Field programs using drifting ice buoys to track ice movement show that the equipment is generally durable. The cost of retrieving a malfunctioning buoy may approach the unit costs (similarly so for moored monitors), thus, the ease of maintenance is rated poor. Though access to tne data collected by the buoy systems (via satellite DCS) is good, the complicated deployment schemes and maintenance difficulties detract from the simplicity of the operations. The effectiveness of buoys to monitor the movement of the ice edge remains to be evaluated as one component of a comprehensive ice monitoring program.

The only kind of rig-based radar considered feasible for ice detection in compliance with the operational requirements is ground wave radar whose transmission follow the curvature of the earth and "sees" hazards hidden over-the-horizon. This radar technology is still in the research phase and therefore, little information is available to base a costing analysis.

3.2.4 Summary

This report has shown cost estimates of operating various ice monitoring systems as well as qualitative ratings of each system's , reliability and ease of operation.

The most expensive approach is the aircraft equipped with Synthetic Aperature Radar or Side Looking Radar. Both of these systems provide the necessary information on sea ice characteristics with all weather, day and night capability, which can be delivered to the operator and MMS personnel within three hours after observation. Pulse compression radar, which is an upgrade to standard marine search radar, is far less costly than microwave radar to operate but it does not provide the range of ice information needed to make operation decisions.

Satellite imagery and point observations from buoys have obvious shortcomings in providing the kind of ice information desired but are useful components of an ice observation program employing airborne or satellite microwave radar. The costs involved with receiving and analyzing the NOAA, Landsat, and, presumably, the Geosat satellite information for ice conditions are small in comparison with operating an aerial surveillance program employing microwave radar. Although the costs associated with monitoring the position or ice contact events of either drifting or tethered buoys are relatively low, the expense of development, deployment, and retrieval can be significant.

In the future, SAR satellites will likely satisfy some of the requirements for all-weather ice information if near-real-time data can be generated and easily accessed at the Alaska SAR Facility. The costs of accessing the satellite SAR ice images presently cannot be determined but will ultimately depend upon NOAA’s plans for servicing the commercial sector. Ice edge information derived from passive microwave sensors on future military satellites (and as a complement sensor on some of the satellites carrying SAR) will most likely be available from the NOAA/Navy Joint Ice Center at no cost to the user except for leasing the facsimile equipment and data communication link.

3.3 FEASIBILITY ANALYSIS OF MONITORING SYSTEMS

The monitoring systems examined in this report are rank-ordered in Tables 3-25 and 3-26. The current systems (Table 3-25) and future systems (Table 3-26) were ranked separately because of the uncertainty

TABLE 3-25
RANK-ORDER OF OBSERVATION SYSTEMS CURRENTLY AVAILABLE
FOR MONITORING THE ASSOCIATION OF BOWHEAD WHALES
WITH SEA ICE IN THE BERING SEA

Rank Order	Observation System	Evaluation Criteria[a] 1	2[b]	3	4	5	6	7	8
	Yes (Y), No (N), Possible (P), Conditional ( ), Good (G), Intermediate (I), Poor (P)								
1	SLR/SAR (Airborne)	Y	Y	Y	P	Y	Y	G/G	High
2	NOAA (AVHRR)	Y	N	Y	Y	Y	Y	G/G	Low
3	LANDSAT	Y	N	N	P	Y	Y	I/G	Low
4	P.C. Radar (Airborne)	Y	N	Y	Y	N	P	I/G	High
5	Ship-, land-, rig-based Radar[c]	Y	N	Y	Y	N	P	G/G	High
6	GEOSAT	N	Y	N	Y	N	N	G/G	Low
7	Nimbus 7	N	Y	N	N	P	Y	P/G	Low

a/ An effective observation system must fulfill criteria 1 through 4, listed below. Fulfillment of additional criteria 5 through 7 increases the effectiveness of a system and increases the rank-order. Criteria 5 through 7 are ordered in decreasing priority. Cost had little influence on the ranking since so few systems fulfilled the required criteria.

1. Ice edge
2. All-weather/day or night
3. Observation frequency
4. Reporting times
5. Ice thickness
6. Ice concentration
7. Facility of use/reliability
8. cost

b/ An effective system must fulfill both components of this criterium. Systems that partially met the criterium did not comply with the requirements.

c/ Only ship-based radar was considered because the other forms were not capable of adequately covering a broad geographic area.

d/ Nimbus 7 was ranked lowest because of the low resolution and the unavailability of current data.

TABLE 3-26
RANK-ORDER OF FUTURE OBSERVATION SYSTEMS
FOR MONITORING THE ASSOCIATION OF BOWHEAD WHALES
WITH SEA ICE IN THE BERING SEA

Rank Order	Observation System	Evaluation Criteria[a/] 1	2	3	4	5	6	7	8
	Yes (Y), No (N), Possible (P), Conditional ( ), Unavailable (U), Good (U), Intermediate (I), Poor (P)								
1	SAR Satellites	Y	Y	P	(Y)	(Y)	Y	U/G	U
2	Polar Platforms	Y	Y	P	(Y)	(Y)	Y	G/G	U
3	DMSP[b/]	N	Y	Y	P	N	(Y)	G/G	U
4	Submersible Buoy	Y	Y	Y	Y	N	P	U/G	U
5	Sonobuoy	P	Y	Y	Y	P	P	U/G	U

a/ An effective observation system must fulfill criteria 1 through 4, listed below. Fulfillment of additional criteria 5 through 7 increases the effectiveness of a system and increases the rank-order. Criteria 5 through 7 are ordered in decreasing priority. Cost had little influence on the ranking since so few systems fulfilled the required criteria.

1. Ice edge
2. All-weather/day or night
3. Observation frequency
4. Reporting times
5. Ice thickness
6. Ice concentration
7. Facility of use/reliability
8. Cost

b/ DMSP was ranked low because of low resolution (25 km).

of the latter systems becoming fully operational. The systems were ranked according to the criteria described in the report which included 1) operational requirements, 2) reliability, 3) facility of use, and 4) cost. The systems were qualitatively evaluated relative to these criteria and ranked in an order of decreasing suitability for monitoring the association of bowheads with sea ice.

The ranking process was heavily weighted toward the operational requirements since these requirements must be met for a system to be useful . In particular, the system must be capable of detecting the ice edge, operating during all weather conditions during the day and night, monitoring the area once per day, and reporting the information in a short time period. Systems meeting more criteria in the evaluation received a higher ranking and fewer received a lower ranking. Reliability, facility of use, and cost generally contributed very little to the ranking, since the capability of the various systems to fulfill the operational requirements was unequal and typically overrode these other criteria. Furthermore, the reliability and facility of use of the various systems was generally good except for several systems that already ranked low due to failure to fulfill the operational requirements.

The airborne radar observation systems were ranked highest. Both the SAR and SLR fulfilled the operational requirements and provided measurements of high resolution. Although these systems also had the highest operating costs, they were the only ones of the entire suite of systems examined that fully met the operational requirements.

The remaining systems were ranked lower because they did not fulfill the all-weather conditions, day or night operational requirements except for the Nimbus 7 satellite and Geosat. The former system, however, has a very low resolution, and since the data are not available, it was ranked lowest of all the systems. The Geosat was ranked low because the observation frequency is once per 17 days, although the ice edge can be detected in all weather during day or night. The all-weather condition is a particularly important criteria to fulfill because the Bering Sea. is predominantly cloud-covered during the period when bowhead are present. While the remaining systems, as ranked in decreasing order, were NOAA (AVHRR, IR), Landsat, PC Radar, and ship-land-rig-based systems, they are not feasible ice monitoring systems for the Bering Sea.

In addition to the currently available systems, five of the six future observation systems were rank-ordered (Table 3-26). Ice moored buoys were excluded because they do not fulfill the operational requirements. The highest ranked system was the SAR satellites. While there is uncertainty about their facility of use, they will potentially fulfill the criteria for monitoring bowheads' association with sea ice. The sophisticated instrumentation proposed for this system and the polar platforms will provide additional monitoring opportunities as more information became available for defining the association of bowheads with sea ice. The DSMP satellite also offers many monitoring opportunities, but it was ranked number three because the resolution is lower than the other systems, The rankings of the two types of buoys were low because of the limited spatial coverage of these "point" observation systems.

We recommend the following approach for MMS to follow for monitoring the pack ice in the Bering Sea. A combination of systems including the Geosat, NOAA, and Landsat satellites should be used to monitor the initial advances of the pack ice. The NOAA satellite should be the primary system because it provides high resolution imagery with broad geographic coverage of the Bering Sea. When the southern margin of the pack ice is within 220 km of oil or gas platforms, the airborne radar systems should be instituted to resume the monitoring. This should continue until the pack ice has retreated to the 220 km buffer distance. This approach is the only reliable system currently available to remotely monitor the association of bowheads with sea ice in the Bering Sea.

4.0 RECOMMENDATIONS

4.0 RECOMMENDATIONS

This report provides a framework for recommending additional studies for enhancing the value of the results to more clearly define the association of bowhead whales with sea ice and to reach statistically significant conclusions about this association. A clear definition of the factors governing the winter distribution of whales would improve the capacity to develop mathematical equations to predict bowhead densities in the pack ice. This predictive capability could be linked to a sea ice monitoring program for managing petroleum activities in the bowhead wintering area of the Bering Sea. The recommendations we propose include:

1) Field surveys of known bowhead whale wintering areas should be conducted to increase the sample sizes for observations of pack ice characteristics. Random searches of the pack ice should not be conducted because of the uncertainty of finding whales.

2) Field surveys should include obtaining a photographic record of sea ice conditions that can be compared to observer estimates. This would reduce the variability of the estimates by compensating for observer errors. It also would provide a mechanism for ground verifying ice estimates from satellite imagery.

3) Persistence of open water should be evaluated for more locations for more years from satellite imagery, since this variable appeared to influence bowhead winter distribution. More locations would provide a better measure of bowhead presence or absence in the pack ice and more years would identify the interannual variation of the measurements.

4) Additional studies should be conducted to fully describe the relationship of St. Lawrence and St. Matthew island areas to wintering bowhead whales. These studies should address the characteristics of the pack ice and polynyas around the island. Polynya characteristics that should be further examined include

size, persistence, orientation, and movement relative to wind direction and speed. This should be accomplished through a multiyear study of satellite imagery.

5) Satellite tracking studies of bowhead whales should incorporate monitoring movements of the whales in the Bering Sea.

6) Sea ice monitoring relative to bowhead whale occurrences will require a combination of observation systems. General movement patterns of the pack ice should be monitored from the NOAA satellite system. Once the pack ice reaches a critical distance (220 km) from a petroleum activity, it should be monitored by the SLR/SAR Airborne Radar System. This is the only system capable of monitoring the ice during all environmental conditions, at a spatial resolution and reporting time sufficient to manage petroleum activities relative to bowhead whale occurrences in the pack ice. Supplementary information can be provided from other systems.

The bowhead whale is an endangered marine mammal. The Bering Sea wintering area is an essential component of the bowheads annual range. The current study has provided a broad foundation of the association of bowhead whales to sea ice in the Bering Sea, and an evaluation of current and future observation systems capable of remotely monitoring this association.

5.0
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5.0 LITERATURE CITED

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APPENDIX A

APPENDIX A

ANNOTATED BIBLIOGRAPHY

The annotated bibliography summarizes published and unpublished information about the distribution and association of bowheads in the Bering Sea pack ice. The purpose of the bibliography is to identify sources of information to define this relationship and not to provide a comprehensive review of all bowhead related literature. Pertinent information is identified and summarized according to a format specifically designed to describe the contents of a manuscript or a data base for analysis of the bowheads. The summaries are provided below..

Citation: Aldrich, H.L. 1889. Arctic Alaska and Siberia, or, eight months with the arctic whalemen. Rand, McNally, and Company, Publishers. Chicago and New York.

INTRODUCTION

Purpose: Describe bowhead whaling in the western Arctic and Bering Sea from experiences on a whaling vessel.

Study Area: Bering, Chukchi, and Beaufort seas.

Survey Period: 1887

METHODS

Survey Platform: Whaling vessel

Survey Type: Hunting as the vessel worked its way through the pack ice.

Data Recorded: Location, ice conditions, time period, and number of whales caught were irregularly and only generally recorded.

RESULTS

Survey Conditions: Not usually recorded, but whales were hunted at every possible opportunity.

Effort: Not identified.

Abundance and Distribution: The route followed by whalers while traveling through the Bering Sea to the Beaufort Sea was from Cape Navarin to Indian Point on the Siberian Coast west of St. Lawrence Island. Aldrich reported that bowheads were encountered along this route but whales were seldom taken south of Cape Navarin. This statement may however be a reflection of ice condition hindering captures of whales rather than absence of whales south of Cape Navarin. Table 1 summarizes the catches of bowhead whales for the Bering Sea.

Habitat Use: Bowhead catches and sightings in the Bering Sea were always associated with the sea ice. Ice conditions near catches were seldom described except for that of the following statement where whales were reported in "large leads on the other (north) side of solid pack ice."

Data Applicability: Historical, descriptive account. There is general information on location and ice conditions associated with bowhead sightings or catches.

TABLE 1

ALDRICH, H.L.
ABUNDANCE AND DISTRIBUTION

Page	24	33
Year	1887	1887
Date	Spring	Spring
Location	Bering Sea near ice edge	Bering Sea near Indian Point
Caught or Hit:		
Number	1	1
Species	Bowhead	Bowhead
Vessel	"Young Phoenix"	"Young Phoenix"
Ice Conditions	Large lead on other side of solid ice	In the pack ice

Citation: Bockstoce, J.R. and D.B. Botkin. 1983. The historical status and reduction of the western arctic bowhead whale (*Balaena mysticetus*) population by the pelagic whaling fleet, 1848-1914. Rep. Int. Whal. Comm. Special Issue 5. pp. 109-141.

INTRODUCTION

Purpose: This paper estimates the number of bowheads that existed prior to the commencement of commercial hunting from the daily entries in the logbooks and journals of the whaling industry.

Study Area: The study area was the Bering, Chukchi, and Beaufort seas.

Survey Period: 1848-1914.

METHODS

Survey Platform: Whaling vessels

Survey Type: Commercial hunting

Data Recorded: Pertinent data extracted from the catch records were:

Date	Species
Location (lat./long.)	Number of animals
Wind direction/speed	Sex of animal
Visibility	Age (calf vs. adult)
Ice Cover	

RESULTS

Survey Conditions: Population estimates were adjusted for wind, speed, visibility, and ice conditions.

Effort: Approximately 4,000 whaling logbooks and journals were examined. From these nearly 800 seasonal Arctic cruises were found of which 550 were suitable for analysis. These represented about 20 percent of the voyages to the western Arctic each year. More than 66,000 daily observations were extracted from these documents representing 516 seasonal cruises, which are equal to 19 percent of the total number of whaling cruises conducted in the western Arctic.

Abundance: Between 1849 and 1914 a total of 3,198 whales were caught and 3,573 killed during 19 percent of the voyages. They. estimate from a weighted cumulative catch and kill that 16,600 bowheads were caught and 18,650 were killed. The pre-exploitation size of the bowhead whale population as estimated from the DeLury Method and variations of it was approximately 20,000 (±10,000) animals.

Distribution: Informal accounts suggest that whalers took a few whales as they worked north toward the Bering Strait through the melting floes, but by early June most of the whales had passed them and gone deep into the ice on the migration to the summer feeding grounds in the Arctic Ocean. About 25 percent of the total whales caught were taken before July, primarily in the Bering or Chukchi seas. Records suggest that bowheads were essentially eliminated from a large part of the original range in the Bering Sea, particularly below 60° N. Whalers caught bowheads in the north and southwest Bering Sea during spring, summer, and fall which suggests they fed in this area.

Habitat Use: Logbooks contained some data about ice conditions of the catch locations. A brief description of an analysis of these data show that only four whales were caught when ice covered five-eighths of the visible ocean, and only a small percentage was caught when ice covered one-half of the visible ocean. Most whales were caught under conditions of low percentage of ice cover during moderate winds and visibility. Catches in these ice conditions, however, may have been due to the capacity of a vessel to maneuver and move through areas of low ice cover versus high ice cover. Furthermore, high ice cover provided many opportunities for a whale to escape from a pursuing whaling boat.

Data Applicability: Good information on general bowhead distribution in the Bering Sea, some description of seasonality, and few data on bowhead association with sea ice. Publication identifies ice cover information in the data base, but there is no analysis or presentation of the information. Maps of the catch distribution of bowheads are also provided.

Citation: Bodfish, H.H. 1936. Chasing the bowhead. Harvard University Press, Cambridge, Mass. 281 pp.

INTRODUCTION

Purpose: A narrative of 31 years of arctic whaling by Captain Bodfish.

Study Area: Primarily Bering, Chukchi, and Beaufort seas.

Survey Period: 1880-1911.

METHODS

Survey Platform: Whaling vessel

Survey Type: Hunting as the vessel worked its way through the ice.

Data Recorded: Position, ice conditions, time period, and number of whales caught were irregularly reported in the book.

RESULTS

Survey Conditions: Not usually recorded, but whales were hunted at every possible opportunity.

Effort: Not identified.

Abundance and Distribution: Bowhead whales were found widely distributed in the pack ice of the Bering Sea. Specific catch locations were generally not given but whales were taken near St. Lawrence Island, East Cape, and Indian Point. No mention was made of whales being taken in the open water, south of the pack ice. Table 1 summarizes the sightings and catches of bowhead whales for the Bering Sea.

TABLE 1

BODFISH, H.H.
ABUNDANCE AND DISTRIBUTION

Page	Year	Date	Location	Caught, Hit, or Sighted #	Species	Vessel	Ice Conditions	Comments
33	?	?	Bering Sea	?	Bowhead	"Grampus"	"Bay in the ice filled with soft, mush ice"	
38	?	May	Bering Sea	?	Bowhead	"Grampus" ,	"Broken ice"	"Bowheads will rise in a crack or fissure anywhere they can set their spout holes above water.
176	?	May 12, 13	Bering Sea	3	Bowhead	"Beluga"		
177	?	May 30	East Cape in Bering Sea	1	Bowhead	"Bowhead"	In the ice	
177	?	June 19	East Cape in Bering Sea	1	Bowhead	"Karluk"		
200	?	May 21	St. Lawrence Island	?	Bowhead	"Beluga"	"Plenty of open water"	
204	?	May 14	Bering Sea	1	Bowhead	"Beluga"	In the ice	
219	?	Apr 20	Bering Sea	1	Bowhead	"William Baylies"	"Whale asleep in the lee of some ice"	
220	?	Apr 21	Bering Sea	2	Bowhead	"William Baylies"	In the ice	
220	?	Apr 23	Bering Sea	1	Bowhead	"William Baylies"	In the ice	
221	?	May	Bering Sea, near St. Lawrence Island	5+	Bowhead	"William Baylies"	In the ice	"within sight of Siberia, we raised whales on five consecutive days"
221	?	May 28	Bering Sea	2	Bowhead	"William Baylies"	In the ice	"cow and calf came up in a hole in the ice"
232	?	May 3	Bering Sea	1	Bowhead	"William Baylies"	In the ice	"the floes at this point were tremendous"
235	?	May 21	Bering Sea, Indian Point	1	Bowhead	"William Baylies"	"Ice still very bad"	
248	?	May	Bering Sea, St. Lawrence Island	1	Bowhead	"Bowhead"	In the ice	
248	?	May	Bering Sea, Indian Point	1	Bowhead	"William Baylies"	In the ice	

Bodfish, H.H. (Continued)

Habitat Use: Bowhead sighting and catch locations in the Bering Sea were always associated with the sea ice. Whales were reported in a variety of ice conditions, including “broken ice”, “mush ice”, and “fissures or holes anywhere bowheads can fit their spout holes above water”.

Data Applicability: Historical, descriptive account. There is general information on location and ice conditions associated with bowhead sightings or catches.

Citation: Bogoslovskaya, L.S., L.M. Votrogov and I.I. Krupnik. 1982. The Bowhead Whale off Chukotka: Migrations and Aboriginal Whaling. Rep. Int. Whaling Comm. 32:391-399.

INTRODUCTION

Purpose: This paper summarizes available literature, the author's data, and data provided by the native people of Chukotka. Seasonal migrations off Chukotka are described.

Study Area: The study area was Chukotka from the Gulf of Anadyr to the Chukchi Sea.

Survey Period: The survey period was from mid-June to early November 1969-1980.

METHODS

Survey Platform: The survey vehicle was not identified.

Survey Type: The survey type was not identified.

Data Recorded: There was no information on data recorded.

RESULTS

Survey Conditions: Survey conditions were not addressed.

Effort: Survey dates and locations were not provided.

Abundance: No abundance estimates were made. Sightings from coastal villages ranged from "very few" to "very many" during the year.

Bogoslovskaya, L.S. (Continued)

Distribution: Bowheads migrate from the western Chukchi Sea in late August. These animals may reside in the Sirenikovskaya Polynya (northern Gulf of Anadyr) during winter. Spring migration from this area begins in mid-April and continues through early June. Calves have been observed in the area during spring.

Habitat Use: Many bowheads were observed to migrate in leads between the shore and pack ice. Whales over-wintering in the Polynya moved in accordance with ice movements. The northern coast is reported to be free of ice during winter.

Data Applicability: Very little information about the data base was given making an evaluation of suitability impossible.

Citation: Bogoslovskaya, L.S. and L.M. Votrogov. 1981. Mass wintering of birds and whales in ice lanes in the Bering Sea. [Original in Russian]. Int. Whaling Comm. Dec. SC/33/02.' 3 pages.

INTRODUCTION

Purpose: The purpose of this paper was to study the distribution of whales and birds in the eastern Bering Sea.

Study Area: The study area was the northern Gulf of Anadyr.

Survey Period: The study period was March through June, 1980.

METHODS

Survey Platform: Aerial surveys and interviews.

Survey Type: No survey type was indicated.

Data Recorded: No information on data recorded was given.

RESULTS

Survey Conditions: Survey conditions were not addressed.

Effort: No survey dates or locations were given.

Abundance: No abundance estimates were made. One group of 30 bowhead whales was observed along the ice-free area of the southern Chukotskiy Peninsula. This was a casual observation and does not represent the total population in this area.

Bogoslovskaya, L.S. (Continued)

Distribution: A small population of bowheads winter along the north coast of the Gulf of Anadyr. The population generally migrates into the area during the first week of November and resides until spring. Mating may occur during their residence in this area.

Habitat Use: The bowhead resided in the ice-free "Polynya" of the northern Gulf of Anadyr.

Data Applicability: Due to the observational nature of this data base it does not appear to be suitable for incorporation into the Task A data base.

Citation: Braham, H.W., B.D. Krogman, and G.M. Carroll. 1984. Bowhead and white whale migration, distribution, and abundance *in* the Bering, Chukchi, and Beaufort seas, 1975-78. NOAA Tech. Rept. NMFS SSRF-778. 39 pages.

INTRODUCTION

Purpose: The objectives of this study were to summarize the current state of knowledge on bowhead and white whale populations, define migration routes and timing, and estimate population size from field research and review of the literature in the Bering, Chukchi, and Beaufort seas.

Study Area: The study area included the eastern Bering Sea, the Chukchi Sea east of the USA-USSR 1867 Convention Line, and the Beaufort Sea to the United States-Canadian border at longitude 141°W.

Survey Period: Field studies were conducted from September 1975 through September 1978.

METHODS

Survey Platform: Fixed-wing aerial survey with aircraft altitudes of 70-300 m in the Bering and Chukchi seas. Additionally, ice and land camps were used in the Beaufort Sea.

Survey Type: Aerial surveys were systematic and random strip transects. The strip width was not identified. Land surveys were generally continuous.

Data Recorded: Data recorded for each *sighting* during aerial surveys included species, number of adults and/or calves, local time of sighting, position (to 1 nm^2), perpendicular angular distance from aircraft to animal, animal activity, and environmental data on weather, visibility and ice. Information recorded during ice and land surveys included number of animals, direction of travel, behavior, weather conditions, time of day, and when possible, length of time animals spent at the surface and duration of dives.

RESULTS

Survey Conditions: The survey conditions were not addressed.

Effort: The survey dates and locations applicable to Task A are as follows:

15, 18, 19, 21 MAR76 - St. Lawrence Is. and Bering Strait
6, 8, 9, 12, 13, 15, 17-23 APR 76 - Bristol Bay and St. Lawrence Is.
31 MAR - 3 APR 77 - St. Lawrence Is. and S. Chukchi

Abundance: No absolute abundance estimate was made. Relative abundance was quantified as whales observed in the survey area irrespective of effort, eight bowheads were observed.

Distribution: Distribution of bowheads was determined by plotting observations chronologically and geographically. No bowheads were observed during the March 1976 surveys in the northern Bering Sea. In the April 1976 surveys three bowheads were sighted in the northern Bering Sea with none observed below latitude 63°N. Five bowheads in three groups were sighted during the March-April 1977 surveys; two groups were southwest of St. Lawrence Island and one group was in the Bering Strait.

Habitat Use: Ice, the primary habitat variable for Task A, was recorded during the surveys and some summarization of percent cover was presented. During the March 1976 northern Bering Sea survey, ice coverage was nearly 90 percent and pack ice was thick. Ice was thick between latitude 64° and 65°N and medium thickness occurred below 64°N while coverage was 70-100 percent (80 percent most common) during the April 1976 surveys. No ice data were presented for the March-April 1977 surveys. No association between ice type or cover and bowhead distribution is presented, but the authors cite other papers associating pack ice breakup and spring migration timing.

Data Applicability: This data base appears to be suitable for incorporation into the Task A data base, although sample size is small.

Citation: Brueggeman, J.J., R.A. Grotefendt and A.W. Erickson. 1983. Endangered Whales of the Navarin Basin, Alaska. Envirosphere Co. 73 pp plus appendices.

INTRODUCTION

Purpose: The objectives of this study were to:

1) Assess the winter habitat use of the Navarin Basin by cetaceans;
2) Assess habitat use of the Navarin Basin by endangered whales during the ice-free season.

Study Area: The study area was the Navarin Basin bounded by the U.S.-USSR Convention line to the west, 174°W longitude to the east, 63°N and 58°N latitude to the north and south respectively.

Survey Period: The survey period was from 11 May 1982 through 18 March 1983.

M E T H O D S

Survey Platform: Aerial and vessel surveys *were* conducted. Aerial surveys were flown at 150-230 m altitudes using two helicopters. Vessel surveys were used only when weather conditions precluded flying.

Survey Type: Stratified systematic and random strip sampling with strip width of 0.5 nm.

Data Recorded: Data recorded during the surveys included: number, species, vertical angle of aircraft to animal, direction of travel, relation to aircraft, group size, time, position, and environmental conditions (wind, sea surface temperature, glare, and ice characteristics).

RESULTS

Survey Conditions: Conditions were generally good during surveys.

Effort: The Navarin Basin was surveyed on the following dates:

11 May - 10 June 1982
20 July - 19 August 1982
29 October - 12 November 1982
19 February - 18 March 1983

Abundance: No bowhead whales were observed in the Navar· n Basin during the spring, summer and fall surveys. During the February-March survey, 21-32 bowheads were observed or an estimated 171 ± 113 bowheads.

Distribution: All bowheads observed were sighted southwest of St. Matthew Island in the marginal ice front.

Habitat Use: Bowheads were largely concentrated along the western fringe of the St. Matthew Island Polynya. Most bowheads were observed in 80-100 percent ice coverage predominated by new and young ice. Floe size did not appear to influence bowhead distribution.

Data Applicability: This data base is suitable for incorporation into the Task A data base.

Citation: Brueggeman, J.J. 1982. Early spring distribution of bowhead whales in the Bering Sea. J. Wildl. Manage. 46(4):1036-1044.

INTRODUCTION

Purpose: To investigate the early spring distribution of bowhead whales in the Bering Sea.

Study Area: The study area was in the pack ice of the northwest Bering Sea, including the marginal ice front from St. Matthew Island to Cape Navarin.

Survey Period: The survey was conducted from 2 March through 13 April 1979.

METHODS

Survey Platform: Aerial and vessel surveys were conducted. Aerial surveys were flown at 150-230 m altitude using two helicopters. Vessel surveys were used only when weather conditions precluded flying.

Survey Type: Stratified systematic paired strip sampling was used with a strip width of 1.8 km.

Data Recorded: The data recorded during the surveys included: location of sighting, ice concentration, floe size, visibility, effort, reaction to aircraft, and animal sighting information.

RESULTS

Survey Conditions: Survey conditions were generally good to excellent.

Effort: The Bering Sea between pack ice south and west of St. Lawrence Island to the ice edge was stratified into three zones and surveyed from 2 March through 13 April 1979.

Abundance: During the surveys, 109 bowheads representing an estimated 176 whales were observed.

Distribution: Approximately 75 percent of the observed whales occurred near St. Matthew and St. Lawrence Islands. Approximately 60 percent of the 109 animals were observed in the marginal ice front, 38 percent in the northern zone, and 3 percent in the central zone.

Habitat Use: Whales appeared to be attracted to areas with 3-4 okta ice, characteristic of the areas near St. Matthew and St. Lawrence Islands. Most whales, however, were in 5-6 okta ice which was most available. No whales were observed in open water.

Data Applicability: This data base is suitable for incorporation into the Task A data base.

Citation: Cook, John A. 1926. Pursuing the whale: A quarter-century of whaling in the Arctic. Houghton Mifflin Company, Boston, MA and New York, NY. 334 pp.

Re: Chapters I-IX, pp 1-122.

INTRODUCTION

Purpose: Personal, descriptive, yearly account of the whaling industry from 1879-1916 by a seaman/captain of various whaling vessels.

Study Area: Includes whaling in the Bering Sea, Arctic, and off Japan.

Study Period: 1879-1896 (chapter I-IX), yearly account.

METHODS

Study Platform: Casual observations made onboard whaling barks and observations of catches and adventures of other barks.

Survey Type: Casual observations.

Data Recorded: Records date, vessel, numbers of whales caught, generally the location caught (sometimes as specific as latitude/longitude coordinates), and occasionally the species and ice conditions.

RESULTS

Abundance and Distribution: Records numbers caught and sometimes the number caught by other vessels or fleets but doesn't always identify the species caught. Sometimes records sightings of whales not pursued. See Table 1.

TABLE 1

COOK, JOHN A.
ABUNDANCE AND DISTRIBUTION

Page	Year	Date	Location	Caught or Hit #	Caught or Hit Species	Vessel	Ice Conditions	Comments
7			Arctic	1	?	"Josephine"		1 whale taken all season
8	1887		Yellow Sea and Sea of Okhotsk	6	Right	"Coral"		
75	1889	winter	Yellow Sea	3	Right	"John & Winthrop"		
18	1890	AUG4	North Pacific, Kodiak grounds?	1	Right	"John & Winthrop"		
19	1890	AUG 19	North Pacific, Kodiak grounds?	1	Right	"John & Winthrop"		
20	winter 1889- AUG 19, 1890			9	Right or Arctic bowheads	"John & Winthrop"		Catch for the season
21	DEC 1890- NOV 1891			9	Right or Arctic bowheads	"Jesse H. Freeman"		Catch for the season
21	1892	MAR	Before entering the arctic	1	Right	"Jesse H. Freeman"	Arctic, very open of ice	
21	1892	SEP	Arctic	"a few"	?	"Jesse H. Freeman"		
21	1892	OCT 6	Lat 71°15'N; Long 170"10'W	2	?	"Helen Mar"	In heavy ice	
21-22	1892	OCT 6	Lat 71°15'N; Long 170"10'W	1	?	"Jesse H. Freeman"	In heavy ice	Whale went under strip of ice
28	1893	APR 11	Lat 60°40'N; Long 178°30'W				Sighted the ice	
28	1893	APR 18	Lat 62°05'N; Long 177"10'E	1	Bowhead	"Belvedere"	"in ice" - until 6/12	Saw lots of whales Apr 18 through May
28	1893	MAY 12	Lat 61°50'N; Long 177°44'E	1	?	"Belvedere"		
28	1893	MAY 14	In sight of Cape Navarin, Siberia	1	?	"Belvedere"	"thick ice"	
29	1893	MAY 14	In sight of Cape Navarin, Siberia	1	?	"Belvedere"	"thick ice"; heavy, thick, strips of ice	Saw4 whales (spp?)
29	1893	MAY 14	In sight of Cape Navarin, Siberia	1	?	"Navarch"	"thick ice"; heavy, thick, strips of ice	Harpooned one but lost it under the ice
38	1893	AUG 22	Arctic, Herschel Island bore SSW 25 miles	1	Bowhead	"Navarch"		

TABLE 1 (Continued)

COOK, JOHN A.
ABUNDANCE AND DISTRIBUTION

Page	Year	Date	Location	Caught or Hit		Vessel	Ice Conditions	Comments
				#	Species			
41	1893	AUG 22-SEP 9	Arctic, east as far as Cape Dalhousie at the entrance of Liverpool 8ay	13	?	"Navarch"		3 of these taken on 9/6
41	1893	APR 18-OCT 10		17	?	"Navarch"		Total catch
44	1894	APR 16	Lat 61°40'N; Long 178°E			"Navarch"	Solid ice pack	
44	1894	APR 24-26	In sight of Cape Navarin			"Navarch"	Too much ice to go after whales	Saw many whales (spp?)
44	1894	APR 28	In sight of Cape Navarin	1	?	"Navarch"		Whale shot but lost
44	1894	APR 30	From Cape Navarin bore 20 mi NE			"Navarch"	Among ice, too much ice to get whales	Saw whales, (spp?)
44	1894	MAY 3-5	From Cape Navarin bore 20 mi NE			"Navarch"	Among too much ice to get whales; bucking the ice	Saw whales, (spp?)
45	1894	JUN 3-4	Diomede Islands, anchored to ground ice off the islands			"Navarch"	Among too much ice to get whales; bucking the ice	Chased several, none caught, (spp?)
46	1894	JUN 14	St. Lawrence Island	"a few"	?	St. Lawrence natives		
49	1894	AUG 19	Arctic, Herschel Island area	13	?	6 steamers	Heavy ice fields	"Mary D. Hume","Newport", "Balarna","Narwhal", "Grampus", "Karluk"
49	1894	AUG 20	Arctic, off Herschel Island			"Navarch"	Heavy ice fields	Chased whales (spp?), none caught
50	1894	AUG 20	Arctic, off Herschel Island	1	?	"Grampus"	Heavy ice fields	
50	1894	AUG 20	Arctic, off Herschel Island	1	?	"Karluk"	Heavy ice fields	
50	1894	AUG 21	Arctic, off Herschel Island		?	"Navarch"	Heavy ice fields	Chased many (spp?), none caught
50	1894	AUG 21	Arctic, off Herschel Island	?	?	"Newport and "Mary D. Hume"	Heavy ice fields	Each got whales (spp, #?)

TABLE 1 (Continued)

COOK, JOHN A.
ABUNDANCE AND DISTRIBUTION

Page	Year	Date	Location	Caught or Hit #	Species	Vessel	Ice Conditions	Comments
50	1894	AUG 22	Forced to leave grounds				Heavy ice fields coming towards shore in heavy masses	
50	1894	AUG 31	West of Cape Dalhousie			"Navarch"	Thick ice	Saw whales but couldn't catch due to ice (spp?)
50	1894	AUG 31	West of Cape Dalhousie	1	?	"Narwhal"	Thick ice	
51	NAR 1892- SEP 3, 1B94			69	Arctic or bowhead whales	"Narwhal"		
51	1894	SEP 4	West of Cape Dalhousie?	2	Bowhead	"Navarch"	In among strips of ice	Several bowheads sighted. 2 hit; not fastened to
51-52	1894	SEP 5	West of Cape Dalhousie?	1	?	"Navarch"	Between 2 large floes of ice in lane of open water about 1/2 mi wide	Sighted several (at least 6)
53	1894	SEP 6	Lat 70°20'N; Long 136°45'W			"Navarch"		Sighted 1 whale (spp?) but didn't catch it
53	1894	SEP 9	Near King Point			"Navarch"		Saw 2 whales but didn't catch any
54	1894	SEP 11	"All whales seen going in NE direction"; so ship headed NE					
54	1894	SEP 13	NE of King Point?	1	?	"Thrasher"		
54	1894	SEP 14	NE of King Point?	1	?	"Navarch"		
54	1894	SEP 15	NE of King Point?			"Navarch"		1 whale (spp?) chased, not caught
55	1894	SEP 23	Near Herschel Island			"Newport"		Saw "Newport" chasing 1 whale - caught?
55	1894	OCT	Herschel Island				Young ice had formed over the whaling grounds ending the whaling season	
66	1895	JUL 14	North of Cape Bathurst			"Navarch"	Ice floes, many	Chased 1 whale (spp?) but lost in the ice floes
66	1895	JUL 14	North of Cape Bathurst	1	?	"Newport"	Ice floes, many	
66	1B95	JUL 14	North of Cape Bathurst	1	? calf	"Mary D. Hume"	Ice floes, many	Shot it, but lost it

TABLE 1 (Continued)

COOK, JOHN A.
ABUNDANCE AND DISTRIBUTION

Page	Year	Date	Location	Caught or Hit #	Species	Vessel	Ice Conditions	Comments
67	1895	AUG 2	Off of Cape Bathurst			"Navarch"	Ice floes, many	Chased a small whale but unable (spp?) '° get near it
67	1895	AUG 3	Off of Cape Bathurst			"Navarch"	Ice floes, many	Chased a whale, no success (spp?)
67	1895	AUG 6	15 mi north of Cape Bathhurst			"Navarch"	Ice fields	Chased 3 whales (spp.) but no success because whales in among ice fields
67	1895	AUG 7	15 mi north of Cape Bathhurst	1		"Newport"	Ice fields	
67	1895	AUG 7	15 mi north of Cape Bathhurst			"Mary D. Hume"	Ice fields	Saw many (spp?), none caught
68	1895	AUG 13	near Pullen Island			"Navarch"		Saw several spp?), none caught
68	1895	AUG 13	near Pullen Island	1	?	"John & Winthrop"		
68	1895	AUG 15	East of Toker Points			"Navarch"		Saw several spp?), none caught
68	1895	AUG 15	East of Toker Points	1	?	"Newport"		
68	1895	AUG 17	off of McKinley Bay	1	?	"Navarch"		Saw several (spp?)
68	1895	AUG 19	near Baillie Island			"Navarch"		Chased 1 (spp?), not " caught
68	1895	AUG 19	near Baillie Island	1	?	"Mary O. Hume"		
68	1895	AUG 20	off Cape Bathurst	1	?	"Navarch"		
68	1895	AUG 21	off Cape Bathurst			"Navarch"		Chased 1 (spp?), not caught

TABLE 1 (Continued)

COOK, JOHN A.
ABUNDANCE AND DISTRIBUTION

Page	Year	Date	Location	Caught or Hit #	Species	Vessel	Ice Conditions	Comments
70	1895	SEP 9	Geary Island in sight			"Navarch"		Chased 2 (spp?), not caught
70	1895	SEP 9	Geary Island in sight	1	?	"Mary D. Hume"		
70	1895	SEP 10	Geary Island in sight	1	?	"Newport"		
70	1895	SEP 11-13	Offof Pullen Island	1	?	"Navarch"		Chased whales but none caught (spp?), incl. bowhead. One darted (spp?), but lost
70	1895	SEP 13	Off of Pullen Island	1	?	"J.H. Freeman"		caught
70	1895	SEP 16	Off of Pullen Island	1	?	"J.H. Freeman"	large fields of ice came in rapidly from offshore	
7?	1895	SEP 19	Pullen Island to the westward			"J.H. Freeman"	ice close inshore	Saw 1 whale (spp?), but none caught
71	1895	SEP 20	Pullen Island to the westward			"J.H. Freeman"		Chased cow and calf (spp?) but not caught
71	1895	SEP 21	Near Hopper Island	1	?	"J.H. Freeman"		3 whales (spp?) seen, 1 caught
71	1895	SEP 23	Near Hopper Island?			"Navarch"		Saw more than 5 (spp?), but caught none
71	1895	SEP 23	Near Hopper Island?	1	?	"Fearless"		
72	1895	SEP 24	Near Hopper Island?	1	?	"Navarch"		
72	1895	SEP 26		1	?	"Belvedere"		
72	1895	SEP 28	Herschel Island, end of season	6	?	"Fearless"		Caught 6 whales (spp?) for the season
72	1895	SEP 28	Herschel Island, end of season	5	?	"Navarch"		Caught 5 whales (spp?) for the season. Totals for steamers ranged from 3-7 for the season

TABLE I (Continued)

"COOK, JOHN A.
ABUNDANCE AND DISTRIBUTION

Page	Year	Date	Location	Caught or Hit #	Caught or Hit Species	Vessel	Ice Conditions	Comments
110	1896	AUG 1					ice permitted vessels to move eastward as far as McKinley Bay	Saw several (spp?), none caught
110	1896	AUG 3	Baillie Island, Cape Bathlust			"Navarch"		
110	1896	AUG 7	Baillie Island, Cape Bathlust				fce so heavy and closely packed that it's impossible for vessels to go farther north or east	
110	1896	AUG8	Baillie Island, Cape Bathlust	1	? small one	"Jesse H. Freeman"		
110	1896	AUG8	Baillie Island, Cape Bathlust	1	?	"Alexander"		
110	1896	AUG8	Baillie Island, Cape Bathlust	1	?	"Beluga"		Harpooned, but lost it
111	1896	AUG 18	Northeast. of Baillie Island 10-30 mi			"Navarch"	cruised among ice	Saw 1 bowhead, not caught
111	1896	AUG 30	Thetis Islands			"Navarch"	whales seen among ice, large floes	Saw large numbers of whales (spp?)
111	1896	AUG 30	Thetis Islands	1	?	"Navarch"	whales seen among ice, large floes	Harpooned, but lost among large floes
112	1896	AUG 31	Thetis Islands	1	?	"Navarch"	whales seen among ice, large floes	Harpooned, but lost among large floes
112	1896	AUG 31	Thetis Islands	1	?	"Navarch"		
112	1896	SEP 3	Off Point Tangent	2	?	"Narwhal"		Got 2 in the past week
113	1896	SEP 4	Off Point Tangent	1	?	"Beluga"		
113	1896	SEP 7					Following along edge of pack ice	
113	1896	SEP 9	Heading for Herald Island	1	?	"Mermaid"		

TABLE 1 (Continued)

COOK, JOHN A.
ABUNDANCE AND DISTRIBUTION

Page	Year	Date	Location	Caught or Hit #	Caught or Hit Species	Vessel	Ice Conditions	Comments
114	1896	SEP 11	Lat 71°12'N; Long 167°W			"Navarch"	following ice pack	Saw 1 whale (spp?), not caught
114	1896	SEP 12	Lat 71°10'N; Long 172°W	1	?	"Jeanette"	following ice pack	
114	1896	SEP 14	Lat 71″10′N; Long 172°W			"Navarch"	following ice pack	Chased many (spp?), none caught
114	1896	SEP 13	Lat 71″10′N; Long 172°W	1	?	"Jeanette"	following ice pack	
114	1896	SEP 14	Lat 71″10′N; Long 172°W	1	? not bowhead	"Navarch"	following ice pack	Struck and killed 1, but it sunk and they lost it
115	1896	SEP 15	Lat 71″10′N; Long 172°W			"Navarch"	following ice pack	Chased many (spp?), but not caught
115	1896	SEP 15	Lat 71″10′N; Long 172°W	1	?	"Orca"	following ice pack	
115	1896	SEP 16	Lat 71″10′N; Long 172°W			"Navarch"	following ice pack	Chased 1 (spp?), but not caught
115	1896	SEP 16	Lat 71″10′N; Long 172°W	1	?	"Orca"	following ice pack	
-115-116	1896	SEP 17	Lat 70°58'N; Long 171°55'W	1	?	"Navarch"	harpooned among ice	
117	1896	SEP 18	Lat 70°50'N; Long 172°W	3	?	"Jeanette"		Had taken 3 since coming westward
117	1896	SEP 18	Lat 70°50'N; Long 172°W	3	?	"Orca"		Had taken 3 since coming westward
117	1896	SEP 22	Off Herald Island, along edge of ice	1	?	"Beluga"	along edge of ice	Harpooned 1 but lost it
117	1896	SEP 22	Off Herald Island, along edge of ice	1	?	"Thrasher"	along edge of ice	Harpooned 1 but lost it
117	1896	SEP 22	Off Herald Island, along edge of ice	1	?	"Orca"	along edge of ice	

TABLE 1 (Continued)

COOK, JOHN A.
ABUNDANCE AND DISTRIBUTION

Page	Year	Date	Location	Caught or Hit #	Species	Vessel	Ice Conditions	Comments
117	1896	SEP 24	Off Herald Island, along edge of ice	1	?	"Orca"	along edge of ice	Harpooned 1 but lost it
117	1896	SE? 24	Lat 71°20'N, Long 172°40'W	1	?	"Karluk"	along edge of ice	
118	1896	SEP 27	Lat 71°N, Long 173°50'W - southern edge of ice pack	2	?	"Navarch"	at southern edge of ice pack	Harpooned 2, but lost both under ice pack
118	1896	SE? 29	around Lat 71°N; Long 173°50'W	1	?	"Belvedere"	at southern edge of ice pack	
118	1896	SEP 29		1	?	"Narwhal"		Darted 1 but lost it
118	1896	OCT 5	near Lat 70°30'N; Long 172°W	1	?	"Narwhal"		

Habitat Use: Some mention of ice conditions but only occasionally. First ice usually met at approximately latitude 60°N. Mentioned as thick ice, large or small floes, or pack ice. Recorded along with abundance and distribution.

Miscellaneous: There is mention of whales caught in Navarin Basin area (see Table 2 and refer to the Abundance and Distribution section.)

Data Applicability: Historical, descriptive account. There is information on numbers of bowheads caught, location, and ice conditions.

TABLE 2

COOK, JOHN A.
WHALES CAUGHT IN NAVARIN BASIN AREA

Page	Year	Date	Location	Caught or Hit #	Caught or Hit Species	Vessel	Ice Conditions	Comments
28	1893	APR 11	Lat 60°40'N; Long 178°30'W	1	?		sighted the ice	
28	1893	APR 18	Lat 62°05'N; Long 177"10'E	1	Bowhead	"Belvedere"	"in ice" - until June 12	Saw lots of whales from APR 18 -NAY
28	1893	MAY 12	Lat 61°50'N; Long 177°44'E	1	?	"Belvedere"	"in ice"	
28	1893	MAY 14	In sight of Cape Navarin, Siberia	1	?	"Belvedere"	"thick ice"	
29	1893	MAY 14	In sight of Cape Navarin, Siberia	1	?	"Belvedere"	"thick ice", heavy thick strips of ice	Saw4 (spp?)
29	1893	MAY 14	In sight of Cape Navarin, Siberia	1	?	"Navarch"	"thick ice", heavy thick strips of ice	Harpooned 1 but lost it under the ice
44	1894	APR 16	Lat 61°40'N; Long 178°E			"Navarch"	solid ice pack	
44	1894	APR 24-26	In sight of Cape Navarin			"Navarch"	too much ice to go after whales	Saw many whales (spp?)
44	1894	APR 28	In sight of Cape Navarin	1	?	"Navarch"	among ice, bucking the ice field	Whale shot but lost, went under ice
44	1894	APR 30	From Cape Navarin bore 20 mi NE			"Navarch"	among ice - too much ice to get whales. Bucking the ice field	Saw whales (spp?)
44	1894	MAY 3-5	From Cape Navarin bore 20 mi NE			"Navarch"	among ice - too much ice to get whales. Bucking the ice field	

Citation: Fay, F.H. 1974. The role of ice in the ecology of marine mammals of the Bering Sea. In: D.W. Hood and E.J. Kelley, eds. Oceanography of the Bering Sea with emphasis on renewable resources. Univ. Alaska, Fairbanks Inst. Mar. Sci. Occas. Publ. 2:383-399.

INTRODUCTION

Purpose: The purpose of this paper was to summarize the available literature on the relationship between ice and marine mammals.

Study Area: Summarized literature available on the distribution of marine mammals in the Bering Sea. Also describes distribution of ice in the Bering Sea during winter months.

RESULTS

Distribution: The bowhead winters in the *ice* front of the central and southwest Bering Sea. They migrate to the Arctic Ocean from March to May and summer along the edge of the permanent ice pack. Results were derived from secondary data sources.

Citation: Fedoseev, G.A. 1982. Aerial sightings to bowhead whales distribution and their number in the Chukchi and east Siberian seas. Unpublished paper presented at the International Whaling Commission meeting, Brighton, England. 1982. Paper No. SC/34/P523.

INTRODUCTION

Purpose: This paper summarizes sightings of bowhead whales from aerial surveys conducted from 1960 through 1980.

Study Area: The survey area was the Chukchi and east Siberian seas with one survey *in* the Bering Sea.

Survey Period: The survey period was not specifically identified in the paper.

METHODS

Survey Platform: Aerial surveys from fixed-wing aircraft. Some surveys were conducted at 200 m altitude.

Survey Type: The survey type was not identified for most of the surveys discussed in this paper, although one survey used strip sampling with strip width of 1,000 m.

Data Recorded: No information on data recorded was given.

RESULTS

Survey Conditions: Conditions were not reported.

Effort: Most surveys were conducted in the Chukchi Sea with one survey into the Bering Sea in mid-December.

Abundance: During the December Bering Sea survey, 15 bowheads were sighted. During surveys in early October along the northern coast of the Chukotskiy Peninsula, 375 bowheads were observed. These observations represented an estimated 3500 whales.

Distribution: The whales sighted during the December Bering Sea surveys were located south of St. Lawrence Island. Bowheads observed in the autumn Chukchi Sea surveys were among cake ice in the coastal zone. Additionally, bowheads were observed near new forming ice.

Habitat Use: The whales observed in the Bering Sea were at the edge of 7-8 ball ice. This paper concluded that movement away from the Chukchi Sea is directly dependent on ice formation processes.

Data Applicability: The Bering Sea survey from this study may be suitable for incorporation into the Task A data base.

Citation: Hanna, G. D. 1920. Mammals of the St. Matthew Islands, Bering Sea. J. Mammal. 118-122.

INTRODUCTION

Purpose: Survey of mammals on the three islands comprising the St. Matthew Island group.

Study Area: St. Matthew, Hall, and Pinnacle Islands in the Bering Sea.

Survey Period: July, 1916

Survey Platform: Foot surveys.

Survey Type: Ground reconnaissance.

Data Recorded: Not described.

RESULTS

Survey Conditions: Not applicable.

Effort: Six days.

Abundance and Distribution: No bowheads were observed but the author reported that the bones of this species were exceedingly abundant on all beaches.

Habitat Use: No information.

Data Applicability: No quantitative data but observations suggest that St. Matthew Island vicinity was historically used by bowhead whales.

Citation: Kenyon, K.W. 1972. Aerial surveys of marine mammals in the Bering Sea, 6-16 April 1972. Unpublished Manuscript. (Copies available through: Natl. Mar. Mammal Lab., NWAFC, 7600 Sand Point Way N.E., Bldg. 32. Seattle, WA 98115).

INTRODUCTION

Purpose: The purpose of this survey was to obtain information on the distribution and general abundance of the Pacific walrus and all other marine mammals encountered in the Bering Sea.

Study Area: The survey area was from the Bering Strait to the Alaska peninsula and from the Alaskan coast to Siberian coastal waters.

Survey Period: Surveys were conducted on 7 and 11-16 April 1960.

METHODS

Survey Platform: Aerial surveys were conducted with fixed-wing aircraft at 500 ft altitude.

Survey Type: Systematic and random strip sampling with strip width of 1 nm.

Data Recorded: Information recorded during surveys was: time, number of animals inside and outside of survey strip, percent ice cover, and ice type.

RESULTS

Survev Conditions: Weather during the surveys was generally clear.

Effort: The survey dates and locations are:

7 APR 72 - Norton Sound
11 APR 72 - N. Bering to Gulf of Anadyr
12 APR 72 - St. Lawrence Is. to St. Matthew Is.
13 APR 72 - Bristol Bay and to the west
14 APR 72 - Bristol Bay north to Bethel
15 APR 72 - St. Lawrence Is.
16 APR 72 - Norton Sound

Abundance: Only one bowhead whale was observed during the surveys.

Distribution: The one bowhead was observed just north of St. Lawrence Island in young ice in about 60 percent cover.

Habitat Use: Ice conditions (ice cover and type) were recorded periodically during the surveys. These data are presented in this paper.

Data Applicability: This data base will be suitable for incorporation into the Task A data base.

Citation: Kenyon, K.W. 1960. Aerial surveys of marine mammals in the Bering Sea. 23 February to 2 March 1960 and 26-28 April 1960. Unpublished manuscript. (Copies available through: Natl. Mar. Mammal Lab., NWAFC, 7600 Sand Point Way N.E., Bldg. 32. Seattle, WA 98115).

INTRODUCTION

Purpose: The purpose of this paper was to record observations of marine mammals, especially the Pacific walrus (Odobenus rosmarus divergent), in the Bering Sea during late winter and early spring and to estimate the walrus and bearded seal populations based on his information.

Studv Area: The study area included the Bering Strait to northern Bristol Bay from the Alaskan Coast to the Gulf of Anadyr.

Study Period: Surveys *were* conducted from February to April 1960.

METHODS

Survey Platform: Aerial surveys flown in fixed-wing aircraft at 500-700 ft altitudes.

Survey Type: Systematic and random-strip sampling with strip width of 1 mi.

Data Recorded: The data recorded was not addressed.

RESULTS

Survey Conditions: The survey conditions were not reported.

Effort: The survey dates and locations are:
23 FEB-2 MAR 1960 - north Bering Sea south of St. Lawrence Island.
26-28 APR 1960 - Central to northern Bering Sea.

Abundance: No abundance estimate was made for bowheads. Only one bowhead whale was observed.

Distribution: One bowhead whale was seen in a lead about 55 miles north of St. Lawrence Island on 27 April. No other whales were observed.

Habitat Use: Ice conditions were classified using the classification system given by Armstrong & Roberts (1956) but was not presented in this report. No association of whale distribution with ice type is presented.

Data Applicability: This data base may be suitable for incorporation into the data base but no decision can be made until the data base is actually examined.

Citation: Krogman, B. D., H.W. Braham, R.M. Sonntag and R.G. Punsly. 1979. Early spring distribution, density, and abundance of the Pacific walrus (*Odobenus rosmarus*) in 1976. Unpublished manuscript. (Copies available through: Natl. Mar. Mammal Lab., NWAFC. 7600 Sand Point Way N.E., Bldg. 32. Seattle, WA 98115.)

INTRODUCTION

Purpose: The objectives of this study were to assess walrus distribution on the pack ice during the period of maximum extent of ice coverage in the Bering Sea.

Study Area: The study area includes the Bering Sea above 56°N and the Chukchi Sea to 68°20'N.

Survey Period: Field studies were conducted from March through June 1976.

METHODS

Survey Platform: Aerial surveys were conducted from a fixed-wing aircraft at 300-1000 ft (generally 500 ft) altitudes.

Survey Type: Random and systematic strip sampling with strip widtns of 0.868 nm or 1 nm depending on aircraft type.

Data Recorded: Information recorded for each sighting included species, number of adults and/or calves, geographical position (to 1 nm^2), perpendicular angular distance from aircraft to animal, animal activity and environmental conditions including weather, visibility, and ice.

RESULTS

Survey Conditions: Survey conditions were not specifically addressed.

Efforts: The survey dates and locations applicable to Task A are as follows:

15,18,19,& 21 MAR 76 St. Lawrence Is. - Bering Strait
13,15,19-23 APR 76 St. Lawrence Is.
8,9,11,17,19-21,23 APR 76 S. Bering
12-15,17,18,21-26 APR 76 Central-M Bering

Abundance: No bowhead sightings reported.

Distribution: Not described.

Habitat Use: Not described.

Data Applicability: The March 76 and 13-23 April 76 surveys were reported in Braham et al. 1984. The 8-23 April 76 survey was an ADFG survey and will be suitable for incorporation into the data base. The 12-26 April 76 survey was a survey by Russian scientists and may not be available for incorporation into the data base.

Citation: Leatherwood, S. A.E. Bowles, and R.R. Reeves. 1983. Endangered whales of the eastern Bering Sea and Shelikof Strait, Alaska: results of aerial surveys, April 1982 through April 1983 with notes on other marine mammals seen. Hubbs-Sea World Research institute. San Diego, California. 319 pp.

INTRODUCTION

Purpose: Determine endangered whale abundance, distribution, habitat use, and behavior in the eastern Bering Sea and Shelikof Strait.

Study Area: Eastern Bering Sea and Shelikof Strait. Survey area in the eastern Bering Sea was Bristol Bay and the southeast Bering Sea south of 62° N and east of 174° N, and Shelikof Strait between Kodiak Island and the Alaska Peninsula.

Survey Period: Not given.

METHODS

Survey Platform: Twin engine aircraft including Grumman Goose and Twin Otter.

Survey Type: Stratified systematic and random transect sampling with line-transect estimation procedures.

Data Recorded: Data recorded during the surveys included: time, position, species, number, sighting cue, initial behavior, response to aircraft, swim direction, number of calves, and environmental conditions.

RESULTS

Survey Conditions: For periods when bowheads were most likely to be present, the percentages of the total distances surveyed during sea conditions less than or equal to Beaufort 3 were as follows:

74 percent for mid to late March
65 percent for January
74 percent for mid February to early March

Effort: For periods when bowheads were most likely to be present the effort was:

1,000 nm for mid and late March
1,135 nm for January
956 nm for mid February to early March

Abundance: One group of seven bowhead whales was seen on 31 March, 1982 southeast of St. Matthew Island at 60° 05'.6 N, 171°36.8' W.

Distribution: Although surveys were conducted from 174°00 W to the coast of Alaska between 62°00 N and the Alaska Peninsula, the single bowhead sighting was near St. Matthew Island.

Habitat Use: The whales were at least 6 nm into the pancake ice and about 23 nm south of where the ice conditions changed to extensive broken floes. From monthly summaries of ice conditions based on satellite imagery, the whales appeared to be at least 26 nm north of open water and 23 nm south of heavy pack-ice. The whales were in 36 fathoms of water.

Data Applicability: Single sighting of seven bowheads can be included in the distribution to better describe the winter range.

Citation: Scammon, Charles M. 1874. The Marine Mammals of the Northwestern Coast of North America. J.H. Carmany Company, San Francisco, CA 319 pp.

Re: Chapter V pp 52-65 only.

INTRODUCTION

Purpose: Descriptive (natural history) account of marine mammals and the whaling activities off the northwestern coast of North America written by a whaling captain. Includes a chapter (Chapter V) devoted to the bowhead or great polar white whale.

Study Area: Consists of area in which whalers pursued bowheads, including the Bering Sea. Bowhead whales were seldom seen in the Bering Sea south of latitude 55°N.

Study Period: Whaling accounts from 1840's-1870's.

METHODS

Study Platform: Casual observations made onboard whaling barks, records from whaling captains and records from ship logs.

Survey Type: Casual observations.

Abundance: Very little said and vague (i.e., "many whales...").

Distribution: Gives general location that whalers found bowheads, but no numbers associated with the location. The bowhead whale was seen and pursued from Nova Zembla to eastern Siberia. They inhabited the Sea of Okhotsk south of latitude 54°N, and Spitsbergen in the Arctic. They were found as far west as Davis Strait. Bowheads were seldom seen in the Bering Sea south of latitude 55°N. They were found in the Arctic Ocean adjoining the Bering Sea. Bowheads were formerly taken off Karaginski Island, latitude 59*N. They were also pursued along the coast of the Kamchatka Peninsula, around the Kurile Islands and in the Sea of Japan. The animals can pass from the Atlantic to the Pacific Ocean.

Habitat Use: Some information on ice conditions recorded. Bowheads preferred to be among scattered floes or borders of ice fields rather than in open water. Whales were divided into three age/size classes, the third class containing the smallest whales - these generally were found among broken floes the first of the season and were known to break through ice three inches thick that formed over the water between the floes. Whalers moved north as fast as the broken floes permitted, keeping close to shore as possible to be on the best whaling ground. He suspected that the whales wintered at the southern edge of the winter ice barrier. He knew of no records of whales being captured south of winter ice fields. Called "ice whales".

Miscellaneous: - Whalers met the ice at approximately latitude 60"N around May 1. The Bering Sea was sufficiently clear of ice from approximately July 1-20 for fleets to get to the Arctic as high as latitude 72°N.

Miscellaneous: (Cent inued)

- In 1848 the American bark "Superior" under Captain Roys was the first vessel to work through Bering Strait to the Arctic Ocean.
- Classification of bowheads of the Arctic went as follows:
  1st Class - largest, brown color, averaged 200 barrels oil
  2nd Class - smaller, black, averaged 100 barrels oil
  3rd Class - smallest, black, averaged 75 barrels oil

Data Applicability: Historical, descriptive account.

Citation: Tomilin, A.G. 1957. Mammals of the U.S.S.R. and Adjacent Countries. Volume IX. Cetaceans. Izd. Akad. Nauk. SSSR, Moskva, 756 pp. [In Russian.] (Transl. by Isr. Program Sci. Transl, 1967, 717 pp; available from Natl. Mar. Mammal Lab., NWAFC, 7600 Sand Point Way N.E., Bldg. 32. Seattle, WA 98115.)

Re: pp 5-42

INTRODUCTION

Purpose: Account of natural history of cetacea including species identification key and notes on the whaling industry.

Study Area: Worldwide including Chukchi, Bering, and Beaufort seas and the Sea of Okhotsk.

Studv Period: N/A.

METHODS

Study Platform: Literature review plus study of preserved specimens.

Survey Type: Literature review.

Data Recorded: Natural history, morphometrics, distribution and migration routes, history of whaling.

RESULTS

Abundance: N/A.

Distribution: Gives range but numbers are not associated with location. Tomilin divides Greenland right whales into three stocks based on a review of the literature. These are Stock I: The Spitsbergen stock, which migrated from the eastern coast of Greenland and isles of Iceland and Jan Mayen to Spitsbergen. From Spitsbergen some returned to the Denmark Strait by the same route and some moved along the western coasts of Spitsbergen, turning to the northeastern portion of Greenland and along the eastern coast of Greenland to the Denmark Strait. This stock occurred as far as Nova Zembla.

Stock II: The West Greenland stock, which migrated from the Davis Strait to Baffin Bay; as far north as Smith Sound, also Lancaster Sound and around Baffin Island and Cockburn Land.

Stock III: The Bering-Chukchi stock, migrated from the Beaufort *Sea* along the Alaska Peninsula to the Chukchi Sea and then through the Bering Strait to the Bering Sea and back. They were also seen in autumn in regions of Cape Serdtse-Kamen, Cape Shmidt, Wrangell island, and Herald Bank. In winter, some were seen in the Sea of Okhotsk. It is possible that a few penetrated the East Siberia Sea and Laptev Sea. See Table 1.

Habitat Use: The Bering-Chukchi stock winter in the Bering Sea (Gulf of Anadyr; near St. Lawrence and Karaginski Island). They migrated as far south as the Aleutians, Kamchatka, and Sea of Okhotsk (near Tauiskaya Bay, in Penzhinskii, and Shantarskii Bays). In the spring, as the ice receded, they passed through the Bering Strait to the Chukchi Sea and along the coast of Alaska to the Beaufort Sea. They spent the first half of summer far from the coastline of the Chukot Peninsula *and* some remained at the ice edge in the

TABLE 1

TOMILIN, A.G.
DISTRIBUTION

Year	Date	Location	Caught or Hit		Vessel	Ice Conditions	Comments
			#	Species			
1913		Between Wrangel and Herald Islands	22	Greenland	"Belvedere"		Reported by F.P. Slabodzyan. He also said that this region was the best in the Chukchi Sea for hunting whales.
1940	JAN	Off of Point Hope			F. Rainy		F. Rainy reports that in Jan 1940 at least 20 whales were spotted daily.
1933		Bering Strait, off of Sireniki Village			Sireniki Village		Native hunters
1924-1932		Off of Netekenishvin and Enurmin Villages	6		Netekenishvin and Enurmin Village		Native hunters

Habitat Use:
(Continued) Beaufort Sea through summer. Others migrated to the Wrangell and Herald Island regions and some as far west as the East Siberian Sea. In winter, they followed the edge of the ice, descending to the Bering Sea via the Bering Strait. Some solitary whales wintered between Cape Chaplin and Cape Stoletie. They migrated nearer the coastline during the autumn migration. Whales prefer areas with partial ice cover. They can break ice cover 20-30 cm thick and can push ice floes apart.

Miscellaneous:
- In the region of the Bering Sea the whaling industry existed mainly in the Gulf of Anadyr near St. Lawrence and Karginksii Islands.
- Records sightings and catches made by native populations.
- Between 1788 and 1879 an average of 8,000 bowheads were taken each year from all three stocks of bowheads. Bowheads were not discovered in the Bering Sea until 1843.
- From 1804-1876 American whalers off Chykot, Kamchatka and Sea of Okhotsk took 194,000 bowheads and Pacific right whales. From 1911-1930 only five bowheads were taken off the northwestern coast of America.
- Stocks mix - proven by harpoon record

Data Applicability: Historical account. Gives some general information on abundance, catch and ice conditions.

Citation: Zenkovich, B.A. 1954. Around the world after whales. Gov. Publ. of Geogr. Lit., Moscow, U.S.S.R. [Original in Russian.] (Transl. by L.A. Hutchinson, Translation and Interpretation, Central Duplicating Service, La Jolla, CA. 408 pp.)

Re: Chapters 17 (pp 272-290) and 19 (pp 310-337).

INTRODUCTION

Purpose: Descriptive, historical account of the whaling industry around the world and possible extermination of the animals. Includes a chapter concerning right and bowhead whales (Chp. 17). Includes some natural history and status of population information.

Study Area: Worldwide historical account. Includes occurrence of bowheads in the Bering Strait, Bering Sea, Chukchi Sea, Kurile Islands area and along the Kamchatka Peninsula.

Study Period: Historical account covering whaling industry from first known whaling activities to 1932.

METHODS

Study Platform: Literature review plus 3-year cruise in 1932, documenting whaling activities worldwide.

Survey Type: Casual observations, literature review.

Data Recorded: Records range of animals, natural history, population estimates, catch estimates, hunting techniques.

RESULTS

Abundance: Records population and catch estimates sometimes by location. At time of cruise the Chukchi natives estimated bowhead population at 100. See Table 1.

Distribution: Numbers usually not associated with a specific location. The only mention of the Bering Sea area is that from 1849-1850, 200 Greenland whales were caught in the Bering Strait.

Habitat Use: No detailed description of ice conditions. Chukchi natives said that bowheads appeared in Bering Strait in early November or October if the winter was especially cold and there was heavy ice. Whales wintered on the southern fringe of the ice, among floes, south of Anadyr Gulf on the Asiatic side of the Bering Sea. Southern extent unknown but observed as far south as Cape Kronotsky. Spring, northward migration depended on movement of ice and has been observed to occur as early as April. May - Cape Kronotsky, along Kamchatka and in Oliutorsky Gulf and east to 165° longitude. June-July - the bulk of whales were in Bering Strait and Anadyr Gulf. August - near Pribolof Islands and Northern Deep Bay - but at this time of year most whales were in Chukchi Sea from Wrangel Island to Cape Barrow.

Miscellaneous:

Data Applicability: Historical account. Some information on population size and numbers caught. Information on migration route.

TABLE 1

ZENKOVICH, B.A.
ABUNDANCE

Page	Year	Date	Location	Caught or Hit #	Species	Vessel	Ice Conditions	Comments
273	1935?		Walrus Bay, 150 miles offshore in the Kamchatka Sea	1	smooth whale	Capt. Zarva		Either the Japanese or Okhotsk type
277	1937?	early June	Kamchatka Sea	2	smooth whale - Okhotsk type	"Avanguard"		
280	during migration		Off of Uelen, Naukan, Dezhnero, Chaplino, and Sireniki Villages in the Chukchi Sea		Polar whales	Native hunters	on southern edge of *ice* pack, in open water among floes	Eskimo hunters report no more than 10 spouts of bowheads together in the last decade. Used to he tens of spouts. Now no more than 100 bowheads in the area.
285	during migration		Chukchi Sea		Polar whales	Chukchi whalers		Chukchi whalers killed more than 10,000 whales in one season
310	1669-1787		8ay of 8iscay		Polar whales	Dutch Fleet		100,000 killed by Dutch plus 100,000 more killed by other nations during this time period
312	1680-1689		around Spitsbergen		Greenland			10,000 killed
312	1697		between Spitsbergen and Greenland					1,888 whales killed
312	1718-about 1818		Davis Strait		Green lands			Hunted in Davis Strait
313	1843		Sea of Ukhotsk around Shantarsky Islands		Greenlands			Hunted in Okhotsk Sea
313	1848		Chukchi Sea		Greenland			Hunted in Chukchi Sea
314	1753-1773		Around S. Africa, New Zealand, Australia, and Tasman Sea		smooth whale			14,000 killed/year for 20 years
314	1804-1817		Southern waters			American fleet		Killed 193,522 whales
326	1847-1861		Near Shantarsky Islands, many in Tugursky, Ulbansky, and Usalginsky 8ays					50 whales taken each day

TABLE 1 (Continued)

ZENKOVICH, B.A.
ABUNDANCE

Page	Year Date	Location	Caught or Hit #	Species	Vessel	Ice Conditions	Comments
327	1852-1853	Off of Finland	15	?	Russian-Finnish Company "Shomi"		
327	1852-1853		1	? small one	"Turko"		
327	1852-1853	Sea of Okhotsk	9	Bowheads	"Turko"		Reported by first mate
" 329	1849-1850	Bering Strait	200	Greenlands			
331	1864-1873	Off mouth of Kutin and Tugar Rivers of Turgursky Bay	85	?			
334	DEC 14, 1889-MAR 22, 1890	Wrangel and America Bay	23	?			
334	1890	Near Korea	50				
335	1904-1905	Chukchi Sea			Chukchi natives		Chukchi natives killed about 10/year
336	1925-1926	Off Kamchatka and Chukchi shores from Cape Lopatka to Cape Stone-Heart. Mainly in Kronotsky Gulf and near Komandorskie Islands	570		Norwegians		

APPENDIX B

APPENDIX B
DEFINITION OF SURFACE VISIBILITY CATEGORIES USED DURING AERIAL AND VESSEL SURVEYS[a/]

Category	Definition
Excellent	Surface of water calm, a high overcast solid enough to prevent sun glare. Beaufort = O, visibility greater than 5 km. Marine mammals will appear black against a uniform gray background.
Very good	May be a light ripple on the surface or slightly uneven lighting, but still relatively easy to distinguish animals at a distance. Beaufort = 1 or 2, visibility greater than 5 km.
Good	May be a light chop, some sun glare or dark shadows in part of survey track. Beaufort less than or equal to 3, visibility less than or equal to 5 km. Animals up close (300 m or less) can still be detected and fairly readily identified.
Fair	Choppy waves with some slight whitecapping, sun glare or dark shadows in 50 percent or less of the survey track. Beaufort less than or equal to 4, visibility less than or equal to 1 km.
Poor	Wind in excess of 15 kt, waves over 2 ft with whitecaps, sun glare may occur in over 50 percent of the survey track. Beaufort less than or equal to 5, visibility less than or equal to 500 m. Animals may be missed unless within 100 m of the survey trackline, identification difficult except for larger species.
Unacceptable	Wind in excess of 25 kt; waves over 3 ft high with pronounced whitecapping. Sun glare may or may not be present. Beaufort greater than or equal to 6 or visibility less than or equal to 300 m. Detection of any marine mammal unlikely unless observer is looking directly at the location where it surfaces. Identification very difficult due to improbability of seeing animal more than once.

a/ Surface visibility classification was taken from the National Marine Fisheries Service's Platform of Opportunities Program (Consiglieri and Bouchet 1981).

APPENDIX C

APPENDIX C
SEA ICE CLASSIFICATION USED DURING AERIAL AND VESSEL SURVEYS[a/]

Category	Description
Ice thickness	
New ice	less than or equal to 10 cm
Young ice	10-30 cm
1st year ice	greater than or equal to 30 cm
Ice type	
Grease ice	A later stage of freezing than fragile ice (fine spicules or plates of ice suspended in water) when the crystals have coagulated to form a soupy layer on the surface. Grease ice reflects little light, giving the sea a matt appearance.
Slush (Brash)	Snow which is saturated and mixed with water on ice surfaces, or as a viscous floating mass in water after a heavy snowfall.
Pancake ice	Predominately circular pieces of ice from 30 cm to 3 m in diameter, and up to about 10 cm in thickness, with raised rims due to the pieces striking against one another.
Floes	Any relatively flat piece of ice 10 m or more across.
Small floe	less than 10 m across
Medium floe	10-30 m across
Large floe	30-100 m across
Vast floe	100-200 m across
Giant floe	greater than 200 m across
Ice Concentration	The ratio of tenths or eighths of the sea surface actually covered by ice to the total area of sea surface, both ice-covered and ice-free, at a specific location or over a defined area.

[a/] Ice description were taken from the World Meteorological Organization (1970). Ice floe sizes were modified from the World Meteorological Organization according to definitions of National Oceanic and Atmospheric Administration.

APPENDIX D

TABLE 1

Record of Bowhead Whales Encountered in Bering Sea During March-April 1'979

Date	Number	Location	
3-05-79	5	6225N	17630W
3-05-79	3	6224N	17633W
3-05-79	1	6223N	17635W
3-05-79	1	6222N	17636W
3-05-79	2	6217N	17647W
3-05-79	2	6217N	17647W
3-05-79	1	6226N	17637W
3-05-79	1	6237N	17654W
3-05-79	1	6237N	17651W
3-05-79	1	6237N	17645W
3-12-79	1	6152N	17819W
3-16-79	1	6042N	17305W
3-16-79	4	6037N	17323W
3-16-79	2	6037N	17323W
3-16-79	1	6037N	17323W
3-16-79	1	6037N	17323W
3-16-79	2	6038N	17318W
3-17-79	1	6034N	17326W
3-17-79	1	6036N	17321W
3-17-79	1	6036N	17319W
3-17-79	3	6035N	17321W
3-17-79	1	6033N	17324W
3-17-79	1	6032N	17324W
3-17-79	3	6032N	17324W
3-18-79	1	6044N	17317W
3-18-79	2	6044N	17317W
3-18-79	1	6044N	17318W
3-18-79	1	6043N	17319W
3-18-79	1	6042N	17319W
3-18-79	1	6040N	17320W
3-18-79	3	6039N	17320W
3-18-79	1	6039N	17319W
3-18-79	1	6030N	17319W
3-18-79	1	6029N	17319W
3-18-79	1	6026N	17326W
3-18-79	1	6026N	17326W
3-18-79	1	6027N	17326W
3-la-79	1	6030N	17325W
3-18-79	1	6030N	17325W
3-18-79	1	6030N	17325W
3-18-79	1	6031N	17325W
3-18-79	3	6035N	17325W
3-18-79	1	6036N	17325W
3-18-79	5	6036N	17325W
3-18-79	6	6038N	17325W
3-18-79	2	6038N	17325W
3-18-79	1	6039N	17325W

TABLE 1 (Continued)

Date	Number	Location	
3-18-79	1	6038N	17326W
3-18-79	5	6043N	17326W
3-18-79	1	6045N	17326W
3-18-79	2	6045N	17326W
3-18-79	1	6047N	17336W
3-18-79	2	6036N	17335W
3-18-79	2	6031N	17336W
3-18-79	1	6024N	17342W
3-18-79	1	6024N	17342W
3-18-79	1	6025N	17341W
3-18-79	1	6030N	17341W
3-18-79	1	6032N	17341W
3-18-79	2	6032N	17341W
3-18-79	1	6032N	17341W
3-18-79	3	6045N	17352W
3-18-79	1	6037N	17353W
3-24-79	5	6327N	17155W
3-24-79	1	6326N	17155W
3-24-79	1	6327N	17159W
3-24-79	1	6327N	17159W
3-24-79	2	6318N	17152W
3-24-79	6	6317N	17153W
3-24-79	2	6305N	17152W
3-29-79	1	6308N	17153W
3-24-79	1	6308N	17153W
3-26-79	5	6334N	17214W
3-26-79	2	6337N	17222W
3-26-79	3	6337N	17222W
4-04-79	1	6344N	17235W
4-04-79	1	6333N	17340W
4-04-79	1	6332N	17340W
4-04-79	1	6332N	17340W
4-04-79	1	6327N	17338W
4-04-79	1	6322N	17339W
4-04-79	1	6322N	17339W
4-05-79	4	6330N	17352W
4-05-79	2	6333N	17353W
4-0s-79	1	6333N	17352W
4-05-79	1	6334N	17352W
4-05-79	1	6336N	17353W
4-05-79	1	6338N	17421W
4-05-79	1	6403N	17440W
4-06-79	1	6355N	17511W
4-06-79	2	6401N	17549W
4-07-79	2	6330N	17443W
4-07-79	1	6324N	17435W

TABLE 1 (Continued)

Record of Bowhead Whales Encountered in **Bering Sea During February-March** 1983

Date	Number	Location	
3-12-83	3	6017N	17352W
3-12-83	1	6017N	17400W
3-12-83	1	6009N	17420W
3-12-83	1	6009N	17420W
3-12-83	7	5955N	17420W
3-12-83	12	5954N	17420W
3-12-83	2	5955N	17428W
3-12-83	2	6000N	17428W
3-12-83	1	6023N	17352W
3-12-83	1	6017N	17357W
3-12-83	4	6012N	17403W
3-12-83	1	6007N	17410W
3-12-83	1	6005N	17410W
3-12-83	1	6003N	17411W
3-12-83	1	6001N	17416W
3-13-83	1	6007N	17427W
3-13-83	1	6013N	17413W
3-13-83	1	6015N	17403W
3-13-83	4	6017N	17353W
3-13-83	2	6019N	17341W
3-13-83	1	6004N	17416W
3-13-83	1	6004N	17416W
3-13-83	1	6012N	17404W
3-13-83	1	6014N	17401W
3-13-83	1	6012N	17356W
3-13-83	1	6017N	17357W
3-13-83	1	6019N	17356W
3-13-83	1	6010N	17352W
3-13-83	1	6009N	17353W
3-13-83	1	6009N	17353W
3-13-83	1	6017N	17357W
3-15-83	1	5947N	17324W

TABLE 1 (Continued)

Record of Bowhead Whales Encountered in Bering Sea During January 19S6

Date	Number	Location	
1-23-86	1	6032N	17112W
1-23-86	5	6106N	17208W
1-24-86	1	6129N	17247W
1-24-86	1	6116?'3	17148W
1-24-86	1	6129N	17111W
1-27-86	1	6146N	17344W
1-27-86	2	6200N	17324W
1-27-86	4	6143N	17232W
1-27-86	1	6144N	17218W
1-27-86	1	6147N	17214W
1-27-86	1	6 138N	17259W
1-27-86	2	6135N	17308W
1-27-86	6	6135N	17305W
1-27-86	6	6134N	17308W
1-27-86	1	6133N	17304W
1-27-86	1	6137N	17307W
1-31-86	2	6220N	16817W
1-31-86	1	6210N	17109W

APPENDIX E

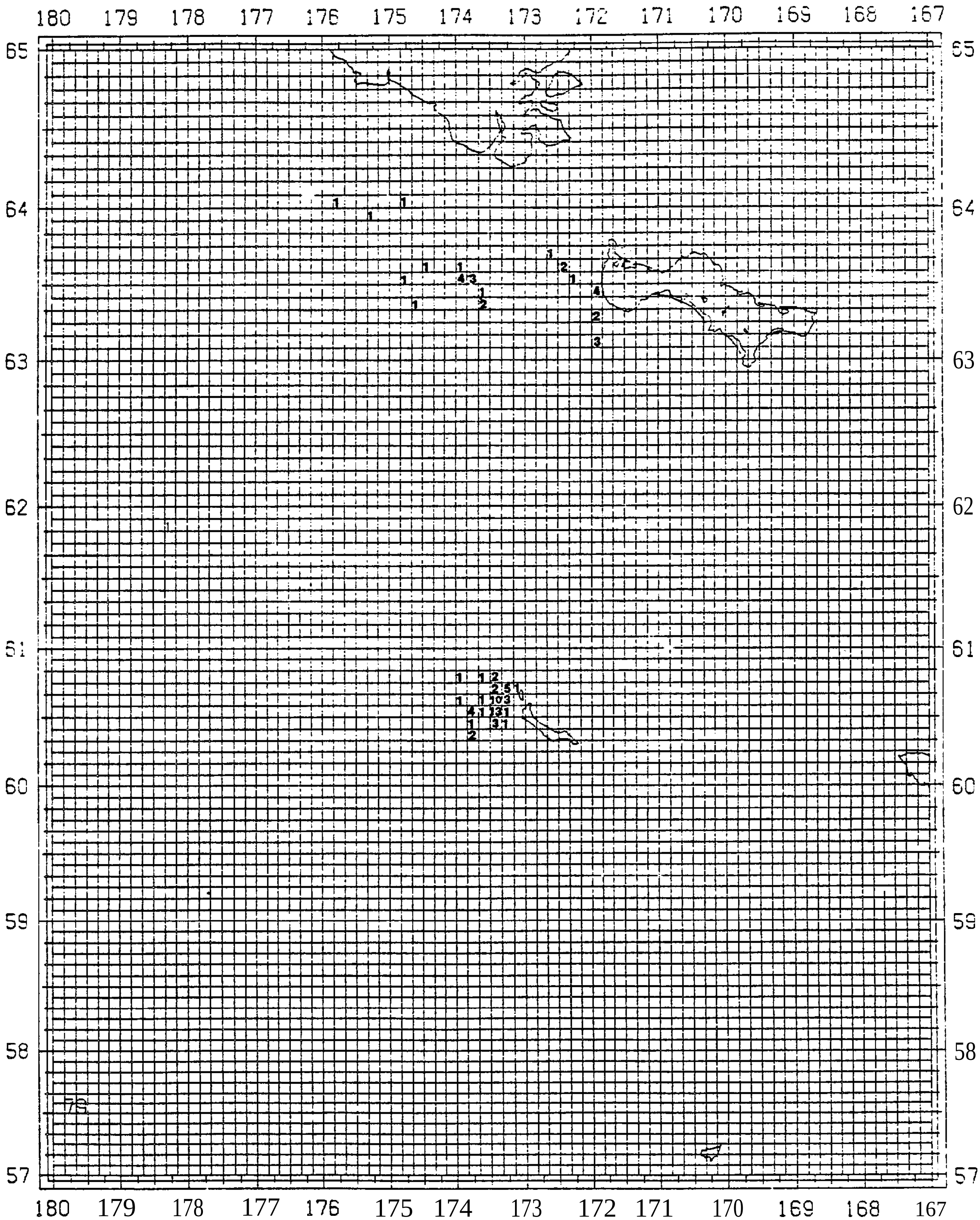

Figure 1 Groups of bowhead whales recorded in 5 min. latitude by 10 rein, longitude **grids** in the Bering Sea, 1979.

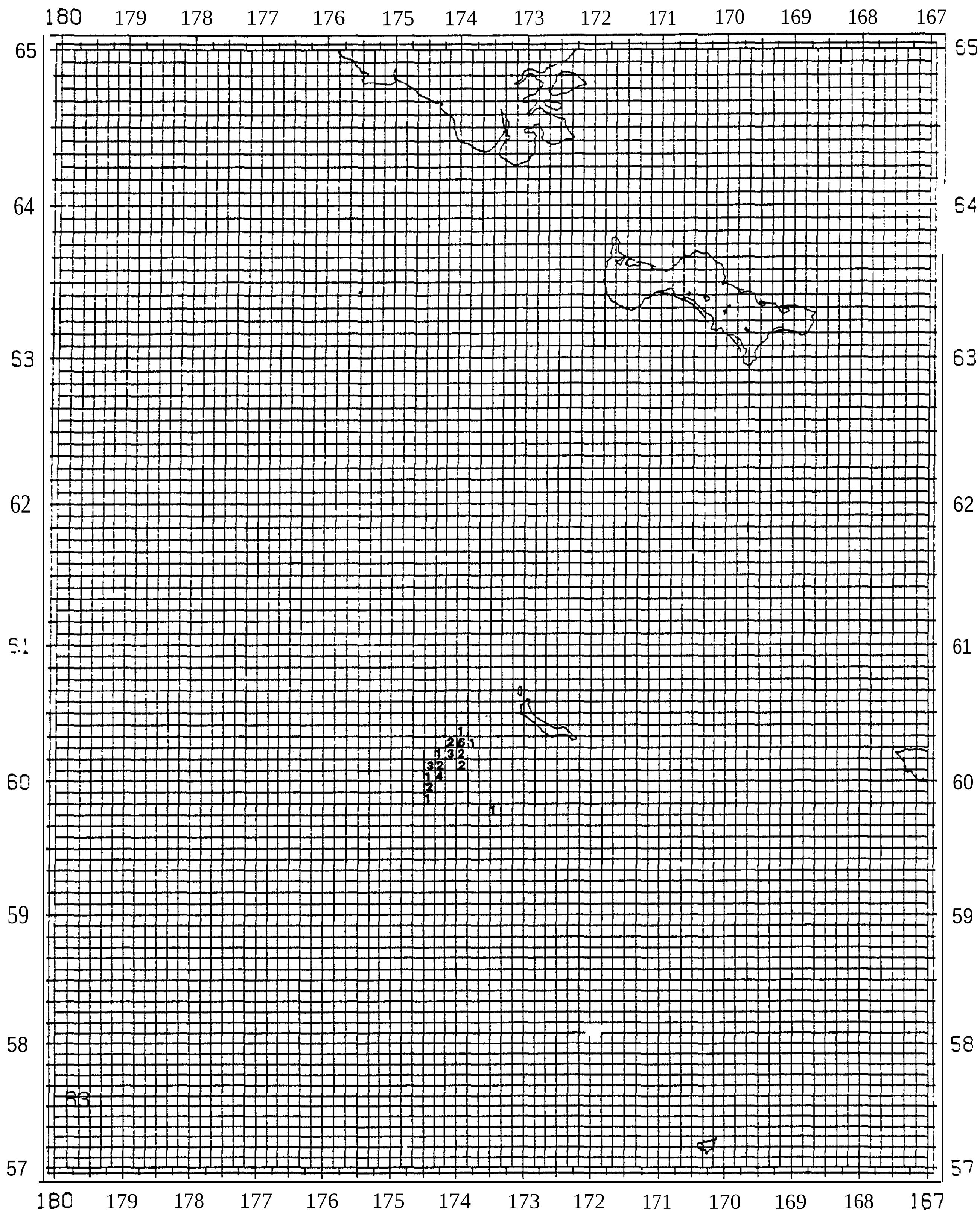

Figure 2 Groups of bowhead whales recorded in 5 min. latitude by 10 min. longitude grids in the Bering Sea, 1983.

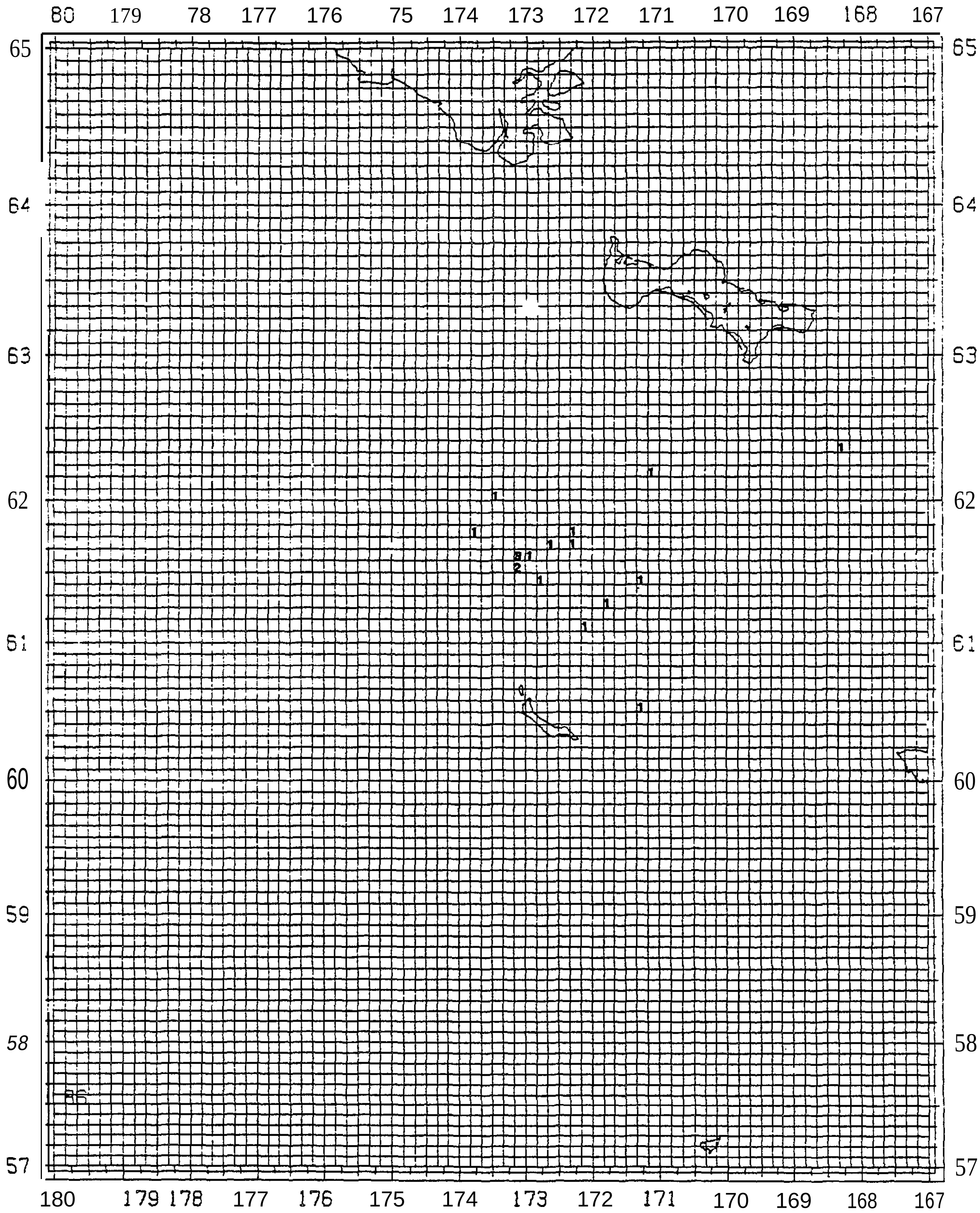

Figure 3 Groups of bowhead whales recorded in 5 min. latitude by 10 min. longitude grids in the Bering Sea, 1986.

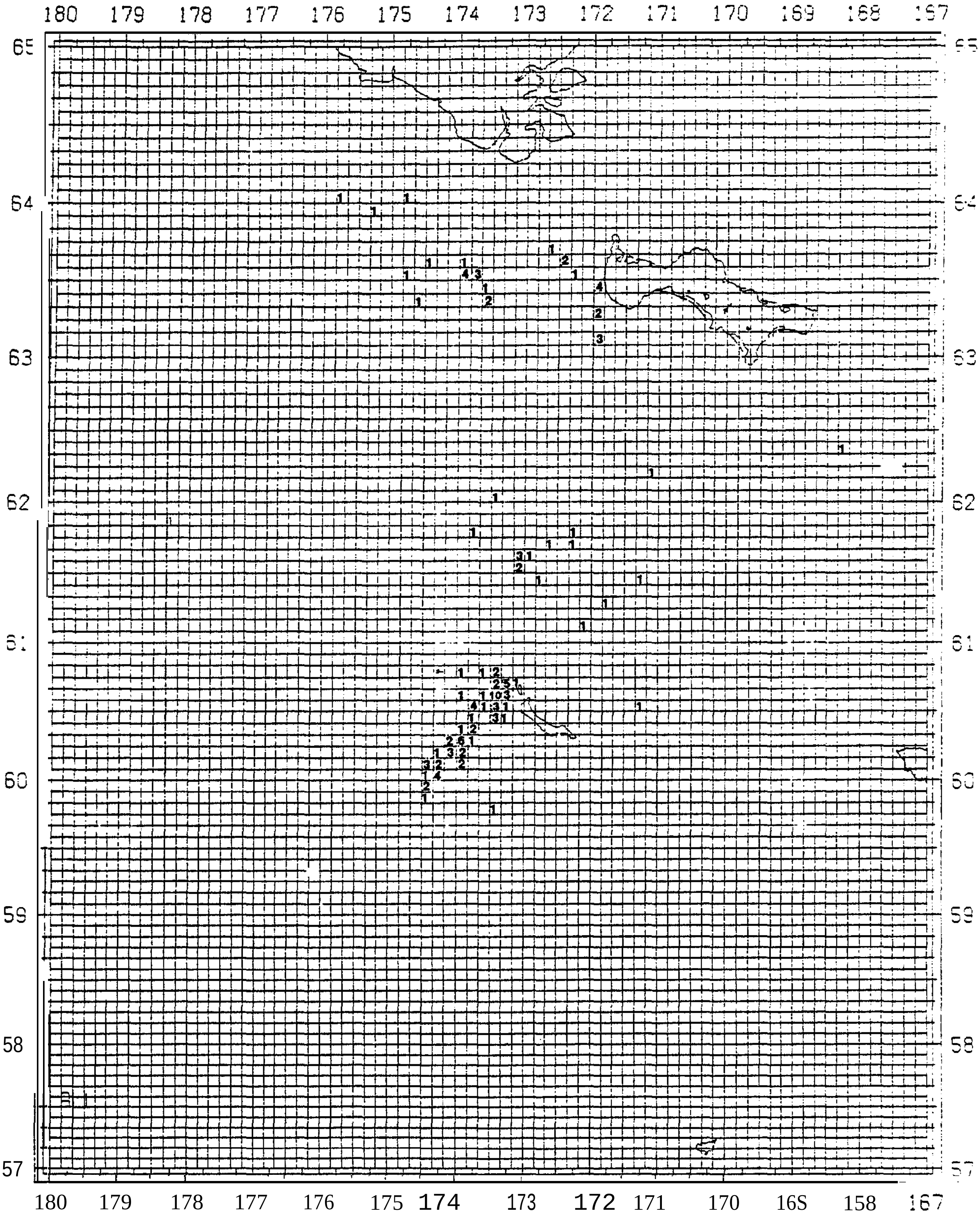

Figure 4 Groups of bowhead whales recorded in 5 min. latitude by 10 min. longitude grids in the Bering Sea - 1979, 1983, 1986.

APPENDIX F

APPENDIX F

EVALUATION OF THE STATISTICAL ANALYSIS OF THE REPORTED RESULTS

by
Douglas G. Chapman

The aim of section 2.0 of this report was to assemble the available information on winter distribution of bowhead whales in the Bering Sea and, as possible, correlate the observed distribution with sea ice conditions. As the report demonstrates, the number of usable data bases was small. The data bases that were usable had to contain information on whale sightings on an objective basis and on ice conditions. These were limited to data from research surveys in 1979, 1983, and 1986. Furthermore, there were differences between some of the measurements in different years or between different platforms that required adjustment and which added considerable noise to the data. This tended to lower the correlations between environmental variables and variables relating to whale distribution.

The primary tool used to develop a quantitative relationship between exogenous variables (i.e., ice characteristics and whale distribution) was multiple regression. In searching for such relationships with a number of possible predictive variables, it is best to approach this in a two step operation. A search is made for the best predictive variables using part of the data. Following the identification of such a best set, their usefulness is validated for the remaining part of the data. This is particularly true when the best predictive variables appear to yield a very high correlation.

In the analysis undertaken in this report, this two step procedure was inappropriate for two reasons. In the first place, the number of transects in which whales were sighted was small and as pointed out above, further complicated by inconsistencies between years or between platforms. Secondly, the proportion of the variation explained by the exogenous variables was quite small. Thus the multiple regressions have limited value from a management point of view.

The two step procedures discussed above should not be confused with the two step procedure carried out in the study and referred to in the report beginning on page 2-15. The two steps used were (1) to determine an equation to predict presence or absence of whales from ice variables, and (2) to predict the number of groups, given that whales were present. Whereas ice concentration had been selected from a large number of variables related to ice as the initial predictor, a study of the survey results suggested that persistence of open water within the pack ice played some role. This is biologically reasonable since whales would conserve energy if they were able to seek out and find protected areas within the ice where open water persists for reasonable periods.

A simple chi square analysis (Table 2-9) demonstrated that indeed whales were found more frequently than expected *in* such persistent open-mixed areas, although not exclusively. Thus, when this variable was added to ice concentration as a predictive variable for either of the relationships stated above, it substantially increased the r^2 for the proportion of the variation explained. The final r^2 *values* were, however, still low, particularly in predicting the presence or absence of whales.

In view of the limited information provided by the multiple regression equations, it is reasonable to consider some other statistical procedures that might provide a better management tool. Non-parametric methods, cluster, or discriminant analysis are procedures that could be considered. Non-parametric methods will in general be less efficient than parametric procedures such as multiple regression and while they may be more robust they cannot provide more precise predictions. Cluster analysis or discriminant analysis will only yield the same quantitative information as multivariate analysis and if the relationship is poor due to excessive noise in the system these will yield the same results.

What are the alternatives for further investigation? Additional observations with a standard protocol to eliminate differences that occurred between the surveys of 1979, 1983, and 1986 will be of some, but only limited additional value. Alternatively, attempts may be made to measure new variables, though at this stage it is difficult to specify what they should be and what new variables will be of predictive value. A third possibility is to modify the scale on which the prediction is to be attempted. It is possible that useful predictions could be made for much larger unit areas. Even this is uncertain until more surveys have been carried out and more information obtained on the winter distribution of the whole bowhead whale stock.