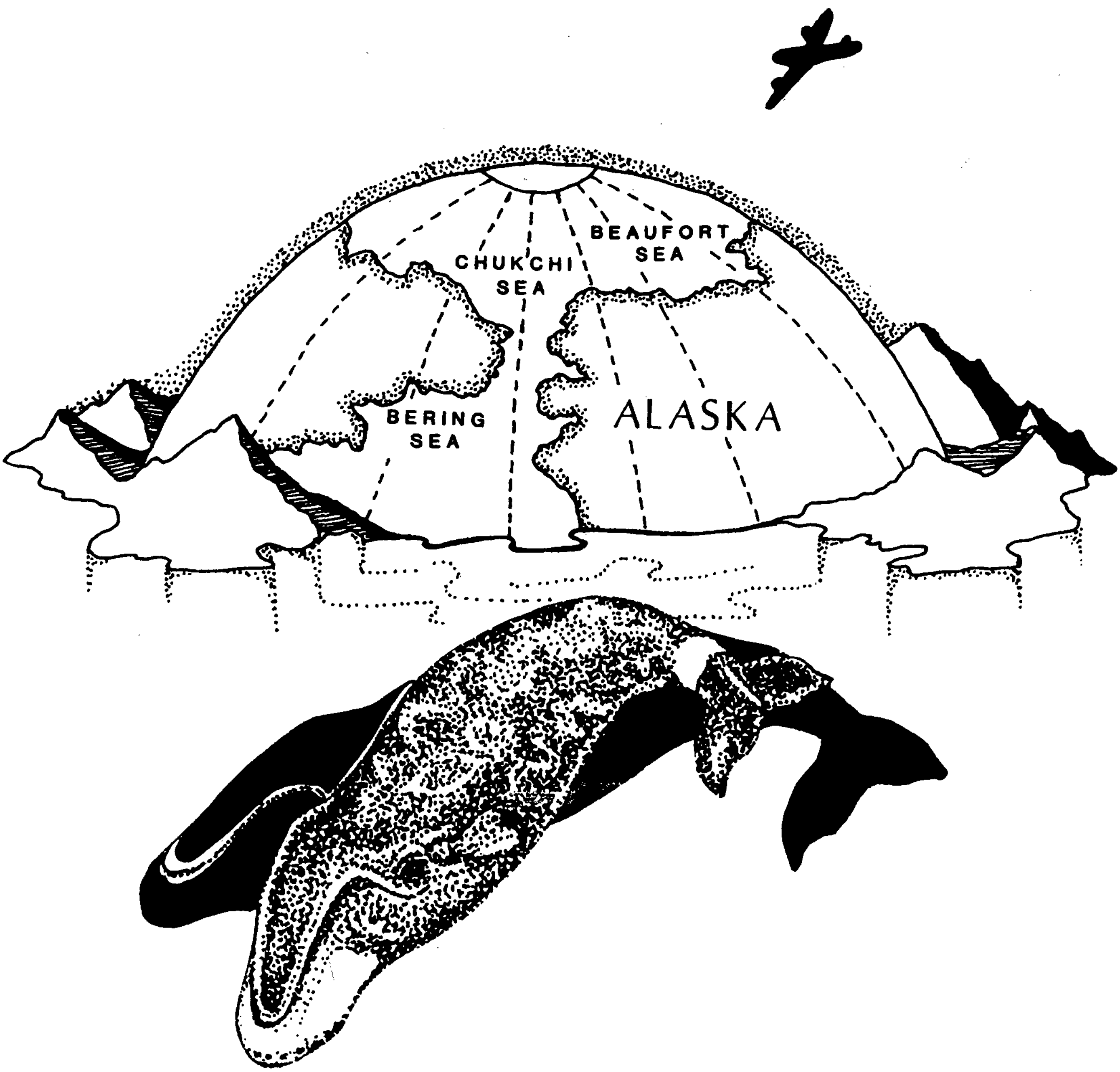
Aerial Surveys of Endangered Whales in the Beaufort Sea, Fall 1993

OCS Study
MMS 94-0032



U.S. Department of the Interior
Minerals Management Service
Alaska OCS Region

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By Stephen D. Treacy, Project Manager
MMS Bowhead Whale Aerial Survey

U.S. Department of the Interior
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Anchorage, Alaska
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ABSTRACT

This report describes field activities and data analyses for aerial surveys of bowhead whales conducted between 1 September 1993 and 28 October 1993 in the Beaufort Sea, primarily between 140°W. and 157°W. longitudes south of 72°N. latitude. General ice cover during September and October 1993 was extremely light, the mildest since fall surveys began in 1979. The number of sightings of bowhead whales (n = 235) and the number of bowhead whales counted (n = 353) during Fall 1993 were the second highest totals for previous project surveys (1987-1993). The bowhead whales, 149 belukha whales, 13 bearded seals, 410 ringed seals, 5 polar bears, 3 Pacific walruses, 2 unidentified cetaceans, and 26 unidentified pinnipeds were observed in 1993 during 166.32 hours of survey effort that included 74.18 hours on randomized transects. The initial sighting of bowhead whales in Alaskan waters occurred on 1 September. Of all bowhead whales observed, half (median) had been counted by 29 September. The peak count (mode) of 56 whales also occurred on 29 September. The last sighting of a bowhead occurred in 0-percent ice in Block 12 on 27 October. An aggregation of 10 bowhead whale pods, many of which were producing visible underwater blows, was observed near the east side of Harrison Bay, just north of Oliktok Point, on 20 September. Estimated median and mean ($\bar{x}$) water depths at the location of bowhead whales sighted on randomized line transects during September and October 1993, 29.0 meters and 35.2 meters, respectively, are consistent with a previously noted trend for whales to be located in shallower water during years of light ice cover.

ACKNOWLEDGMENTS

Project Management

Cleveland J. Cowles, Ph.D., Supervisor
Stephen D. Treacy, Project Manager

Minerals Management Service (MMS) Project Field Scientists

Stephen D. Treacy, Team Leader (Flights 1-18 and 37-41)
Donald Hansen, Team Leader (Flights 19-36)
Kristopher Nuttall, Data Recorder-Observer (Flights 1-18)
John Dunlap, Data Recorder (Flights 19-21)
Susan Zerwick, Data Recorder-Observer (Flights 22-35)
Beverly Sires, Data Recorder (Flights 36-41)
Richard Pomeroy, Primary Observer (Flights 1-6)
Peter Johnson, Primary Observer (Flights 7-16)
Steve Landino, Primary Observer (Flights 17-36)
Donald Hansen, Primary Observer (Flights 37-41)

Technical Support Personnel

John Dunlap, Computer Systems Developer
Steve Landino, Field Equipment Coordinator

Contracting Officer's Administrative Representative - Aircraft Support

Stephen D. Treacy - MMS/Office of Aircraft Services (OAS) IA 14-35-0001-12493

National Marine Fisheries Service (NMFS) Liaison

Ron Morris, NMFS, Anchorage, Alaska

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I. INTRODUCTION

In 1953, the Outer Continental Shelf Lands Act (OCSLA) (43 USC 1331-1356) charged the Secretary of the Interior with the responsibility for administering minerals exploration and development of the OCS. The Act empowered the Secretary to formulate regulations so that its provisions might be met. The OCSLA Amendments of 1978 (43 USC 1802) established a policy for the management of oil and natural gas in the OCS and for protection of the marine and coastal environments. The amended OCSLA states that the Secretary of the Interior shall conduct studies in areas or regions of sales to ascertain the "environmental impacts on the marine and coastal environments of the outer Continental Shelf and the coastal areas which may be affected by oil and gas development" (43 USC 1346).

Subsequent to the passage of the OCSLA, the Secretary of the Interior designated the Bureau of Land Management (BLM) as the administrative agency responsible for leasing submerged Federal lands and the Conservation Division of the U.S. Geological Survey for classification and evaluation of submerged Federal lands and regulation of exploration and production. In 1982, the Minerals Management Service (MMS) assumed these responsibilities.

To provide information used in environmental impact statements and environmental assessments under the National Environmental Policy Act of 1969 (42 USC 4321-4347), and to assure protection of marine mammals under the Marine Mammal Protection Act of 1972 (16 USC 1361-1407) and the Endangered Species Act (ESA) of 1973 (16 USC 1531-1543), BLM funded numerous studies involving acquisition and analysis of marine mammal and other environmental data.

In June 1978, BLM entered into an ESA Section 7 consultation with the National Marine Fisheries Service (NMFS). The purpose of the consultation was to determine the likely effects of the proposed Beaufort Sea Oil and Gas Lease Sale on endangered bowhead (*Balaena mysticetus*) and gray (*Eschrichtius robustus*) whales. After reviewing available information on the two species, NMFS determined that insufficient information existed to conclude whether the proposed Beaufort Sea sale was or was not likely to jeopardize the continued existence of bowhead and gray whales. In August 1978, NMFS recommended studies to BLM that would fill the information needs identified during the Section 7 consultation. Subsequent biological opinions for Arctic Region sales--including a regional biological opinion; a revised opinion relative to the joint Federal/State lease area; and opinions on Sales 71 (issued in 1982), 87 (issued in 1983), 97 (issued in 1987), and Arctic Region sales (issued in 1988)--recommended continuing studies of whale distribution and OCS-industry effects on bowhead whales (USDOC, NOAA, NMFS, 1982, 1983, 1987, 1988). These opinions also requested monitoring of bowhead whale presence during periods when geophysical exploration and drilling are occurring.

Following several years when drilling was limited to the period 1 November through 31 March (USDOI, MMS, 1979), a variable 2-month seasonal-drilling restriction on fall exploratory activity in the joint Federal/State Beaufort Sea sale area was implemented. The period of restriction would vary depending on bowhead whale presence, and "this determination would require development of a monitoring program. . .." (USDOI, MMS, 1982). Subsequently, MMS (Alaska OCS Region) adopted an endangered whale-monitoring plan that required aerial surveys. The Diapir Field Sale 87 Notice of Sale (NOS) (1984) states that "Bowhead whales will be monitored by the Government, the lessee, or both to determine their locations relative to operational sites as they migrate through or adjacent to the sale area" (USDOI, MMS, 1984). The Beaufort Sea Sale 97 NOS (1988) and Beaufort Sea Sale 124 NOS (1991) do not contain a seasonal offshore-drilling restriction but state that "MMS intends to continue its areawide endangered whale monitoring program in the Beaufort Sea during exploration activities. The program will gather information on whale distribution and abundance patterns and will provide additional assistance to determine the extent, if any, of adverse effects to the species" (USDOI, MMS, 1988, 1991).

From 1979 to 1987, the MMS (formerly BLM) funded annual monitoring of endangered whales in arctic waters under Interagency Agreements with the Naval Ocean Systems Center (NOSC) and through subcontracts to SEACO, Inc. On 15 April 1987, a proposal for MMS scientists to conduct aerial surveys of endangered whales was approved by the Associate Director for Offshore Minerals Management. The MMS uses agency personnel to perform field work and reporting activities for the Beaufort Sea on an annual basis. Previous survey reports are available for inspection at the Minerals Management Service, Alaska OCS Region, Library/Public Information Room, 949 East 36th Avenue, Anchorage, Alaska 99508-4302.

The present goals of the ongoing program for monitoring endangered whales are to:

1. Provide real-time data to MMS and NMFS on the general progress of the fall migration of bowhead whales across the Alaskan Beaufort Sea, for use in implementing overall seasonal drilling restrictions and limitations on geological/geophysical exploration;

2. Monitor temporal and spatial trends in the distribution, relative abundance, habitat, and behaviors (e.g., feeding) of endangered whales in arctic waters;

3. Provide annual analyses of long-term interyear trends in the median depth (or north-south positioning) of the migration axis of bowhead whales;

4. Provide an objective wide-area context for management interpretation of the overall fall migration of bowhead whales and site-specific study results;

5. Monitor behaviors, swim directions, dive times, surfacing patterns, and tracklines of selected bowhead whales;

6. Record and map belukha whale distribution and incidental sightings of other marine mammals; and

7. Determine seasonal distribution of endangered whales in other planning areas of interest to MMS.

II. METHODS AND MATERIALS

A. Study Area

The annual survey program is based on a design of random field transects within established geographic blocks in and adjacent to Chukchi and Beaufort Sea sale areas offshore of Alaska. The present study, which was focused on the bowhead whale migration from 1 September 1993 to 28 October 1993, included Beaufort Sea Survey Blocks 1 through 12 (Fig. 1) between 140°W. and 157°W. longitude south of 72°N. latitude.

A large-scale Beaufort Gyre moves waters clockwise from the Canadian Basin westward in the deeper offshore regions. Nearshore surface currents tend to follow local wind patterns and bathymetry, moving from the east in winter, with an onshore component, and to the west in summer, with an offshore component (Brower et al., 1988).

In the Beaufort Sea, landfast ice forms during the fall and may eventually extend up to 50 kilometers (km) offshore by the end of winter (Norton and Weller, 1984). The pack ice, which includes multiyear ice averaging 4 meters (m) in thickness, with pressure ridges up to 50 m thick (Norton and Weller, 1984), becomes contiguous with the new and fast ice in late fall--effectively closing off the migration corridor to westbound bowhead whales. From early November to mid-May, the Beaufort Sea normally remains almost totally covered by ice considered too thick for whales to penetrate. In mid-May, a recurring flaw lead can form just seaward of the stable fast ice, followed by decreasing ice concentrations (LaBelle et al., 1983) and large areas of open water in summer.

Local weather patterns affect the frequency and effectiveness of all marine aerial surveys. The present study area is in the arctic climate zone, with mean temperatures at the Alaskan Beaufort Sea coast communities of Barrow, Lonely, Oliktok, and Barter Island from -0.9°C to -0.1°C during September and -9.7°C to -8.5°C during October. Precipitation in these communities occurred an average of 10 to 34 percent of the time during September (snow with some rain) and 13 to 43 percent during October (almost all snow), with the heaviest precipitation at Barrow and Barter Island during both months. Fog (without precipitation) reduces visibility approximately 11 to 19 percent of the time during September and 6 to 8 percent of the time during October. Mean windspeed in the same communities is from 5 to 6 m per second during September and 5 to 7 m per second during October (Brower et al., 1988).

Sea state is another environmental factor affecting visibility during aerial surveys. Surface waters in the Beaufort Sea are driven primarily by wind. Ocean waves are generally from northerly or easterly directions during September and October, during which time the ice pack continues to limit fetch. Because of the pack ice, significant wave heights are reduced by a factor of 4 from heights that would otherwise be expected during the open-water season. Wave heights greater than 0.5 m occurred in 23.9 to 38.9 percent of observations during September and 14.1 to 37.4 percent during October, with the greater percentage of larger waves (>0.5 m) reported for the eastern third of the study area during both months. Wave heights greater than 3.5 m are not reported within the study area during September or October (Brower, 1988).

The study area contains sufficient zooplankton to support some feeding by bowhead whales. The availability of zooplankton during the fall would be expected to vary between years, geographic locations, and water depths in response to ambient oceanographic conditions. In September 1985 and 1986, average zooplankton biomass in the Alaskan Beaufort Sea east of 144°W. longitude was highest south of the 50-m isobath in subsurface water (LGL Ecological Research Associates, Inc., 1987).

B. Equipment

The survey aircraft was a de Havilland Twin Otter Series 300 (call sign: N302EH). The aircraft was equipped with medium-size bubble windows aft that afforded complete trackline viewing for a port observer and a starboard data recorder-observer. A third observer-navigator occupied the copilot seat, which provided

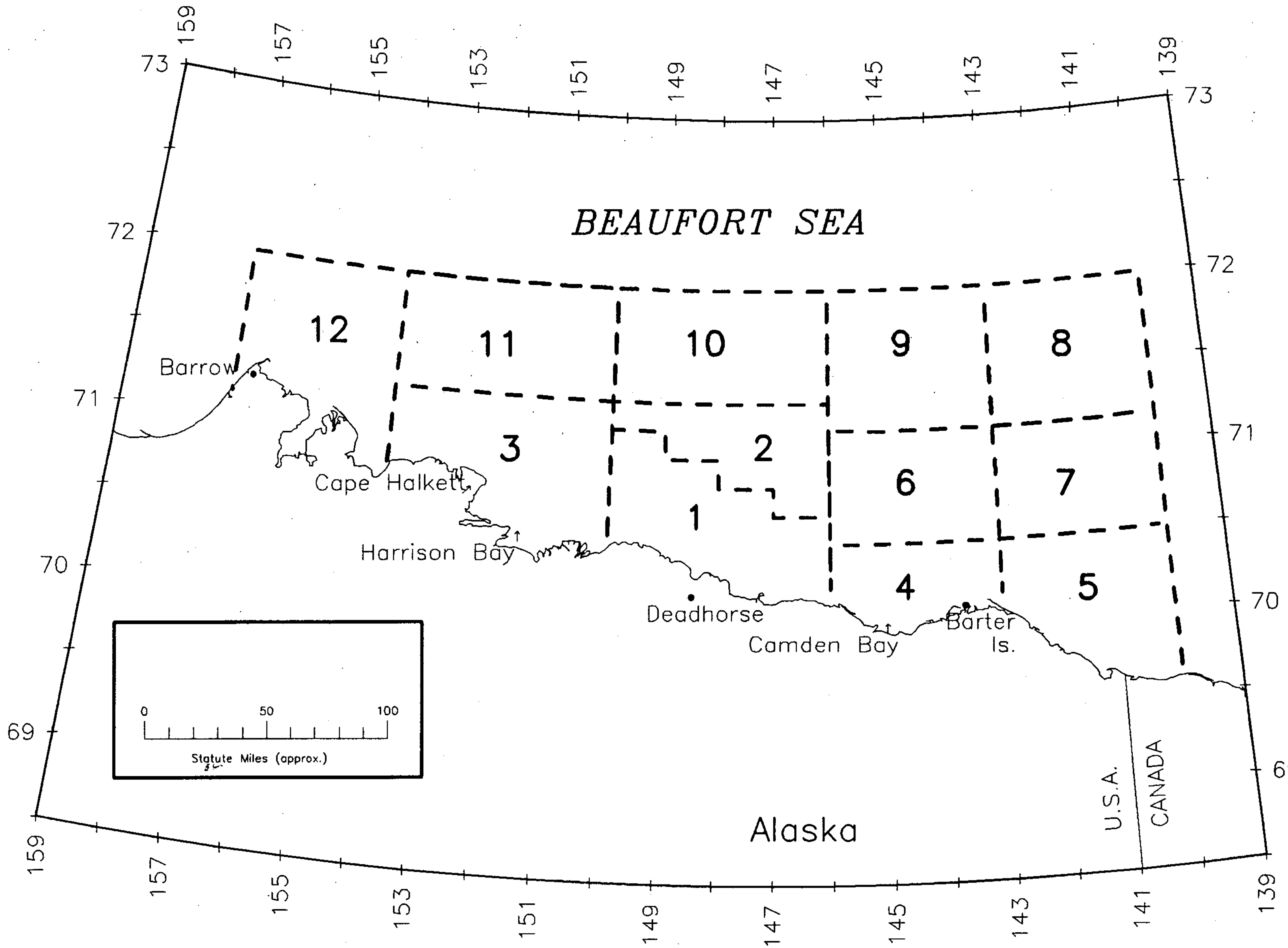

Figure 1. Fall 1993 Study Area Showing Survey Blocks

good forward and side viewing. Each observer was issued a hand-held clinometer (Suunto) for measuring the angle of inclination to the sighting location of endangered whales. Observers and pilots were linked to common communication systems, and commentary could be recorded. The aircraft's maximum time aloft under normal survey load was extended to approximately 8 hours (hr) through the use of a supplemental onboard fuel tank.

Avionics included a Flight Management System (FMS) by ARNAV Systems, Inc., part of which was a Global Positioning System (GPS). The FMS 5000, Model GPS-505, is a worldwide satellite-based system that provides continuous position updating (15-m precision) and survey navigation through preprogramming of transect start and end points. Electronic signals from the GPS were converted into an RS 232 serial stream; and data were polled every second for automatic input of time, latitude, longitude, and flight altitude. The GPS altitude (27-m precision) that was used exceeded the accuracy of the radar altimeter (32 m at the target altitude of 458 m). In the event of a system failure, the team leader could read directly from the aircraft instrument panel for manual entry of this information into the computer. System components required 115-volt alternating current (AC) power, which was supplied by a direct current→AC invertor connected to the aircraft electrical bus.

A portable Mitsubishi MP 286L computing system was used aboard the aircraft to store and analyze flight and observational data. A small, portable Kodak Diconix 150 Plus inkjet printer was used to produce tractor-fed hard copy and to plot onboard flight maps.

Onboard safety equipment included an impact-triggered emergency location transmitter (ELT) installed in the aircraft, a portable ELT in a 6-person Switlik Search and Rescue Life Raft, a portable aircraft-band transceiver, flotation suits, Nomex flight suits, and emergency crash helmets.

Flight-following equipment featured an experimental Radio Determination Satellite System (RDSS) under development by Mobile Datacom Corporation (MDC). Data on latitude, longitude, time, and other parameters were obtained from the aircraft's GPS and broadcast every minute to a satellite that was stationary over the equator at 87°W. longitude. The project helped test several antenna configurations for use in the Alaskan Beaufort Sea during the 1993 field season. One antenna configuration proved relatively successful in being consistently received by the satellite. Real-time satellite signals were relayed to MDC in Clarksburg, Maryland, where OAS queried the RDSS every 15 minutes to obtain current flight-following information. The information was displayed as digital data on a computer screen and in the form of a map for visual tracking of the survey aircraft.

The RDSS was backed up by an onboard aircraft-band radio, used to transmit position data on very high frequency to Deadhorse Flight Service when entering a new survey block and, if possible, when ending southbound transect lines. An onboard high-frequency radio was also used to transmit position data to OAS Flight Operations, Anchorage. The onboard transponder was set at a discrete identification code for radar tracking by air-traffic-control personnel.

C. <u>Aerial-Survey Design</u>

Aerial surveys were based out of Deadhorse, Alaska, from 1 September through 28 October 1993. The field schedule was designed to monitor the progress of the Fall 1993 bowhead migration across the Alaskan Beaufort Sea. All bowhead (and belukha) whales observed were recorded, along with incidental sightings of other marine mammals. Particular emphasis was placed on regional surveys to assess fine-scale shifts in the migration pathway of bowhead whales in this area and on the coordination of effort and management of data necessary to support seasonal offshore-drilling regulations.

Daily flight patterns were based on sets of unique transect grids produced for each survey block. Transect grids were derived by dividing each survey block into sections 30 minutes of longitude across. One of the minute marks along the northern edge of each section was selected at random to designate one end of a transect leg. The other endpoint of the transect leg was determined similarly using a separate randomly generated number along the southern edge of the same section. A straight line, representing one transect leg, was drawn between the two points. The same procedure was followed for all sections of the survey block. Transect legs were then connected alternately at their northernmost or southernmost ends to produce one continuous flight grid within each survey block. The use of random-transect grids is a requirement for later analyses of median water depths at bowhead sightings based on line-transect theory (Cochran, 1963) and analyses of absolute densities based on strip-transect theory (Estes and Gilbert, 1978).

The selection of the survey blocks to be flown on a given day was nonrandom, based primarily on criteria such as reported or observed weather conditions over the study area, the level of offshore oil industry activity in various areas, and a semimonthly flight-hour goal for each survey block. Flight-hour goals were allocated proportionately for survey blocks east of 154°W. longitude and semimonthly time periods based on relative abundance of bowhead whales as determined from earlier fall migrations (1979-1986). Such allocations greatly favor survey coverage in inshore Survey Blocks 1 through 7 and 11 (Fig. 1), since bowheads were rarely sighted north of these blocks in previous surveys. The purpose of these survey-effort allocations was to increase the sample size (n) of whale sightings within the primary migration corridor, thus increasing the power of statistical analysis within these inshore blocks.

Random-transect legs were used for obtaining data to analyze the migration axis, using a line-transect model, and to estimate whale density, using a strip-transect model. Nonrandom surveys were flown to further identify whales and their behaviors when sighted adjacent to a transect line or when in transit to a transect block.

D. Survey-Flight Procedures

During a typical flight, a "search" leg was flown to the target survey block, beginning a series of random-transect legs (above) joined together by "connect" legs, followed by a search leg back to Deadhorse. Surveys generally were flown at a target altitude of 458 m. This altitude was maintained--when weather permitted--in order to maximize visibility and minimize potential disturbance to marine mammals.

A clinometer was used to measure the angle of inclination to each sighting of endangered whales when the initial sighting location was abeam of the aircraft.

When bowheads were encountered while surveying a transect line, the aircraft sometimes diverted from transect for brief (<10-minute) periods and circled the whales to observe behavior, obtain better estimates of their numbers, and determine whether calves were present. Only groups of bowheads seen before diverting from the transect line were included in density calculations.

E. Data Entry

A computer program developed by project personnel was used to record all data. Time of day was maintained by the computer and recorded at each entry. Greenwich Mean Time, local time, latitude, longitude, and altitude as well as a question list and the main menu selections were shown continuously on the computer monitor. The program is menu-driven, facilitating entry of a complete data sequence for sightings of endangered whales. An abbreviated data-entry format was available whenever several whale pods were sighted within a short period of time. To avoid lumping of sightings in areas where whales were extremely concentrated, an even shorter rapid-sighting update was used. A position-update format including data on weather, visibility, ice cover, and sea state was entered at turning points, when changes in environmental conditions were observed, and otherwise within 10-minute intervals. All entries were coded to reflect the type of survey being conducted. Table 1 shows the data-entry sequence used in 1993 and the questions used to prompt entry of observational data. All data entered were simultaneously printed out in hard copy.

For the purpose of discussion, behaviors were entered into one of 13 categories noted on previous surveys. These categories--swimming, diving, milling, feeding, mating, cow/calf association, resting, rolling,

Table 1
Data-Entry Sequence on the Portable Flight Computer

Sequence	Position Update	Large Whale Sightings	Polar Bear/ Belukha Whale Sightings	Other Species
1. Entry number	X	X	X	X
2. Time	X	X	X	X
3. Latitude	X	X	X	X
4. Longitude	X	X	X	X
5. Altitude	X	X	X	X
6. Reason for entry	X	X	X	X
7. Search type	X	X	X	X
8. Species		X	X	X
9. Sighting cue		X		
10. Habitat		X	X	X
11. Behavior		X	X	X
12. Size		X		
13. Total number		X	X	X
14. Calf number		X	X	X
15. Clinometer angle		X		
16. Side of plane		X		
17. Swim direction		X	X	
18. Swim speed		X		
19. Aircraft response		X	X	X
20. Repeat sighting		X		
21. Observer		X	X	
22. Weather	X	X	X	X
23. Visibility right	X	X	X	X
24. Visibility left	X	X	X	X
25. Ice coverage	X	X	X	X
26. Ice type	X	X	X	X
27. Sea state	X	X	X	X
28. Water color	X	X	X	X

flipper-slapping, tail-slapping, spy-hopping, breaching, and underwater blowing--are defined in Table 2. Swimming speed was subjectively estimated by observing the time it took a whale to swim one body length. An observed swimming rate of one body length per minute corresponded to an estimated speed of 1 km/hr; one body length per 30 seconds was estimated at 2 km/hr, and so on. Swimming speed and whale size were recorded by relative category (i.e., still, 0 km/hr; slow, 0-2 km/hr; medium, 2-4 km/hr; or fast, >4 km/hr; and calf, immature, adult, or large adult, respectively) rather than on an absolute scale.

Sea state was recorded according to the Beaufort scale outline in Piloting, Seamanship, and Small Boat Handling (Chapman, 1971). Ice type was identified using terminology presented in Naval Hydrographic Office Publication Number 609 (USDOD, Navy, 1956). Average ice cover within a few kilometers of the aircraft was estimated as a single percentage, regardless of ice type.

F. General Data Analyses

Preliminary data analysis was performed by a computer program--developed by project personnel--that provided daily summations of marine mammals observed, plus calculation of time and distance on transect legs, connect legs, and general search portions of the flight. The analysis program provided options for editing the data file, calculating summary values, and printing various flight synopses.

Application software (Grapher, Golden Software, Inc.) was used to plot daily maps of aircraft tracklines and positions of marine mammals observed. To function as a mapping package, coastlines were mapped using an Altec digitizer; and all points on the maps were based on number of meters north or to one side of a central meridian for Universal Transverse Mercator Zone 6. Observed bowhead distribution was plotted semimonthly over the Beaufort Sea study area. September-October sightings of belukha whales, ringed and bearded seals, and other marine mammals were depicted on separate maps. Maps in this report were plotted on a Hewlett-Packard (HP) Laser Jet II printer equipped with an HP 7475A plotter emulator cartridge.

Ice concentrations in the Beaufort Sea were digitized or hand-drafted as either 0-percent, 0- to 25-percent, 26- to 50-percent, 51- to 75-percent, or 76- to 100-percent ice cover from U.S. Navy-NOAA Joint Ice Center Southern Ice Limit charts.

An index of relative abundance was derived as whales per unit effort (WPUE = number of whales counted/hr of survey effort) per survey block for bowheads and belukhas. The timing of the 1993 bowhead migration through the study area was analyzed as sightings per unit effort (SPUE = number of sightings counted/hr of survey effort) and WPUE per date. Because chance sightings of a few large groups of whales in a short period of time might produce artificially high WPUE values in certain blocks, values based on at least 4.00 hr of survey effort were distinguished when discussing relative abundance between areas.

Habitat preference was depicted as percentage of whales per ice class and percentage of whales per depth regime. Directionality of whale group headings was analyzed using Rayleigh's test (Batschelet, 1972) for all pods, excluding those that were resting, feeding, or milling, and assuming a compass correction of 31°. Probabilities were interpolated from alpha values shown for calculated critical values of Rayleigh's z (Zar, 1984: Table B.32). A generalized bathymetry map was adapted from U.S. Geological Survey Open-file Maps 76-821, 76-822, and 76-823. Additional statistical comparisons, correlations, and regressions (Zar, 1984) were performed as appropriate.

The water depth at each bowhead sighting in the 1982-1993 database was derived using a computer program--DEPTH--that assigned a metric depth value averaged over gridded areas (each 5.6 km^2) in the Beaufort Sea west of 139°W. longitude and south of 72°N. latitude. Values assigned to each grid block were initially subjective and were averaged from depths read from NOAA Provisional Chart 16004.

Raw density estimates were calculated using a computer program--DENSITY--and are presented only for relative comparison with similar values from previous survey reports. The program was based on strip-transect-analyses methods using only sightings made within 1 km of random-transect legs. Density

Table 2
Operational Definitions of Observed Whale Behaviors

Behavior	Definition
Swimming	Whale(s) proceeding forward through the water propelled by tail pushes.
Diving	Whale(s) changing swim direction or body orientation relative to the water surface, resulting in submergence; may or may not be accompanied by lifting the tail out of the water.
Milling	Whale(s) swimming slowly at the surface in close proximity (within 100 m) to other whales, often with varying headings.
Feeding	Whale(s) diving repeatedly in a fixed general area, sometimes with mud streaming from the mouth and/or defecation observed upon surfacing. Feeding behavior is further defined as synchronous diving and surfacing or echelon-formations at the surface with swaths of clearer water behind the whale(s), or as surface swimming with mouth agape.
Mating	Ventral-ventral orienting of two whales, often with one or more other whales present to stabilize the mating pair. Mating is often seen within a group of milling whales. Pairs may appear to hold each other with their pectoral flippers and may entwine their tails.
Cow-Calf	Calf nursing; calf swimming within 20 m of an adult.
Resting	Whale(s) floating at the surface with head, or head and back exposed, showing no movement; more commonly observed in heavy-ice conditions than in open water.
Rolling	Whale(s) rotating on longitudinal axis, sometimes associated with mating.
Flipper-Slapping	Whale(s) floating on side, striking the water surface with pectoral flipper one or many times; usually seen within groups or when the slapping whale is touching another whale.
Tail-Slapping	Whale(s) floating horizontally or head-downward in the water, waving tail back and forth above the water and striking the water surface; usually seen in group situations.
Spy-Hopping	Whale(s) extending head vertically out of the water such that up to one-third of the body, including the eye, is above the surface.
Breaching	Whale(s) launching upwards such that half to nearly all of the body is above the surface before falling back into the water, usually on its side, creating an obvious splash.
Underwater Blowing	Whale(s) exhaling while submerged, thus creating a visible bubble.

estimates were derived by survey block and are presented, with a description of density-estimate methodologies, in Appendix A.

Overall, whale sightings were shown on distribution maps and entered into relative-abundance analyses, regardless of the type of survey leg (transect, search, or connect) being conducted or the prevailing environmental conditions (sea state, ice cover, etc.) when the sightings were made. As with previous reports in this series (Treacy, 1988, 1989, 1990, 1991, 1992, 1993), repeat sightings or sightings of dead marine mammals were not included in summary analyses or maps. Where tables and figures exclude certain data, such exclusions are indicated in the captions.

G. Median and Mean Water Depth at Bowhead Sightings (Analysis Protocol)

The analysis protocol specifying the use of median water depth to detect interannual shifts in the bowhead migration route was initially described in Chapters 4.2.3 and 5.3.3 of "Beaufort Sea Monitoring Program Workshop Synthesis and Sampling Design Recommendations" (Houghton, Segar, and Zeh, 1984). The null hypotheses tested via median-depth analysis were prescribed in Houghton, Segar, and Zeh (1984) as:

Ho_1: The axis of the fall migration of bowhead whales will not be altered during periods of increased OCS activities in the Alaskan Beaufort Sea.

Ho_2: Changes in bowhead migration patterns are not related to OCS oil and gas development activity.

To define the migration axis, a separate file was created for bowhead whale sightings made while on random transects, regardless of distance from the transect line. The Beaufort Sea was divided into three regions in order to analyze east-west components of the known fall-migration corridor. Region I was delimited by 150°W. and 153°30′W. longitudes, south of 72°N. latitude. Region II was between 146°W. and 150°W. longitudes, south of 71°20′N. latitude. Region III was between 141°W. and 146°W. longitudes, south of 71°10′N. latitude (Fig. 2). Because of the bathymetry of the Alaskan Beaufort Sea, a seaward displacement of the fall-migration route would be represented, via this analysis, as a shift to a deeper median depth. Selected isobaths (20 m, 40 m, 100 m, 400 m, 1,000 m, 2,000 m, and 3,000 m), after a Beaufort Sea Planning Area Map (USDOI, MMS, 1985), are included for general reference (Fig. 2).

A computer program--NEWSTAT--was used to analyze the file and describe central tendencies of water depths at bowhead whale sightings. The program was used to calculate median depth, mean depth, Standard Deviation (SD) about the mean, and overall depth range for Regions I, II, and III. NEWSTAT also was used to rank median depths from lowest to highest values. Upper and lower confidence limits for population medians were calculated by hand (Zar, 1984: Table B.26). If sample sizes were large ($n \geq 25$), a large-sample approximation (Zar, 1984: Page 113) was used to calculate the upper and lower limits.

Confidence Intervals (CI) were calculated at the 1-percent level to reduce the probability of incorrectly postulating a change in migration route when no change from other years had occurred. For example, the probability of incorrectly determining that a change had occurred is approximately 23 percent if tested at the 5-percent level, but only about 5 percent if tested at the 1-percent level (Houghton, Segar, and Zeh, 1984).

The NEWSTAT program employed the Mann-Whitney U test to address the question of potential fine-scale shifts in the axis of the bowhead whale fall-migration route. The Mann-Whitney U test is a nonparametric procedure performed on ranked samples (Zar, 1984). The Normal Approximation to the Mann-Whitney Test (Zar, 1984: Page 142) was used to hand-calculate the value of Z for larger sample sizes. A series of Mann-Whitney paired comparisons were made on annual depth values, with each year compared to all others such that annual and/or interannual shifts in migration route from 1982 to 1993 could be evaluated. Similar paired comparisons were made by region (I, II, and III) such that annual variations or potential shifts in median depth could be assessed for these smaller areas. Probabilities were interpolated from alpha values shown for calculated critical values of the Mann-Whitney U distribution (Zar, 1984: Table B.10).

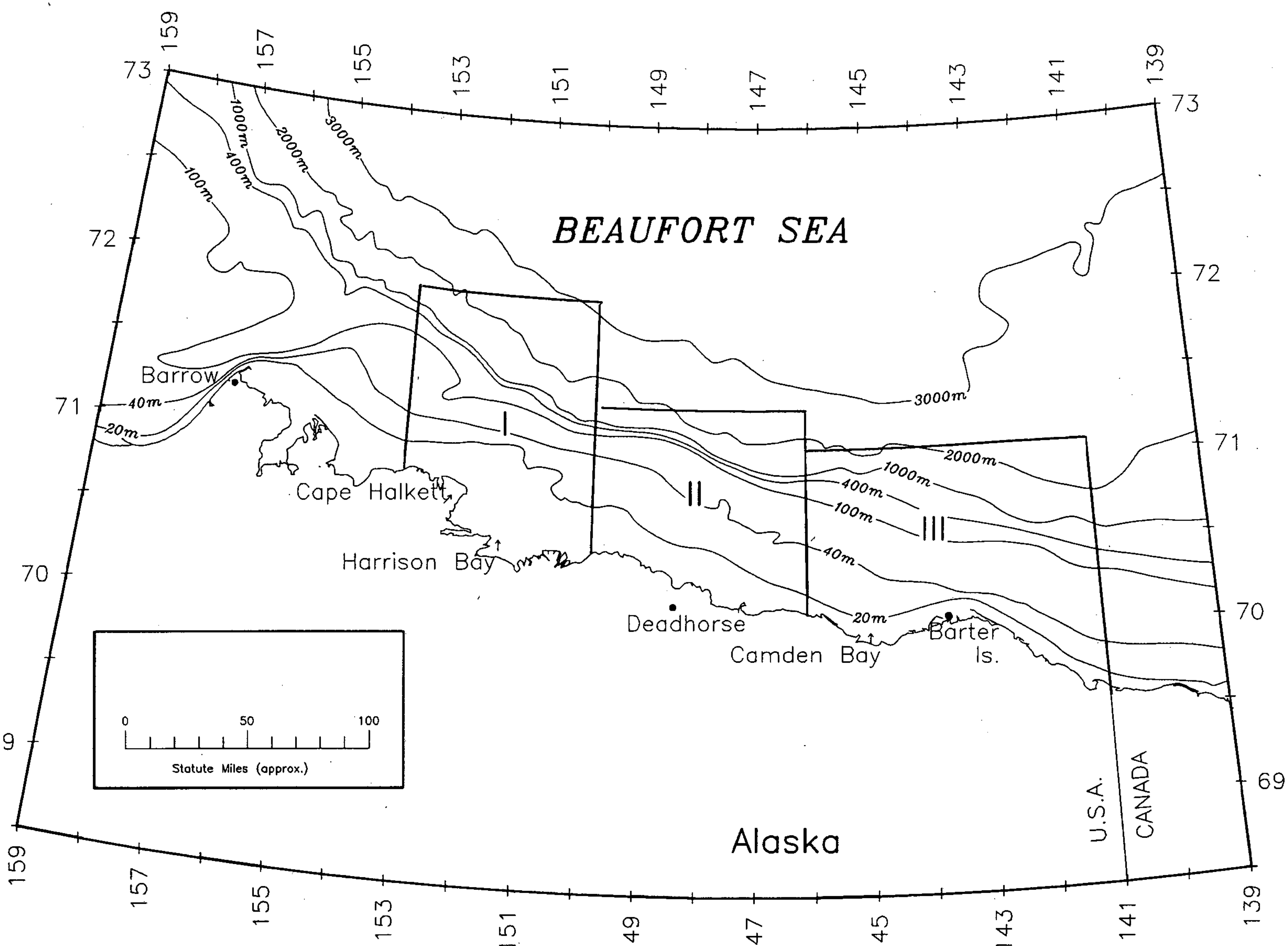

Figure 2. Regions I, II, and III (used in median-water depth analyses) and Selected Isobaths

The NEWSTAT program compared mean water depths at bowhead sightings between years employing an analysis of variance (ANOVA) and the Tukey test (Zar, 1984). Probabilities were estimated as alpha values shown for calculated critical values of the F and q distributions (Zar, 1984: Tables B.4 and B.5).

III. RESULTS

A. Environmental Conditions

General ice coverage in the Alaskan Beaufort Sea was extremely light during the Fall 1993 surveys (Figs. 3-12). Nearshore portions of the study area contained only light ice concentrations (less than 26% ice) from 31 August through 7 September (Figs. 3-5). From 14 September through 19 October, only small patches of sea ice remained south of 72°N. latitude (Figs. 5-10). By 26 October, heavy ice (51-75%) extended south to 71°N. latitude (Fig. 11). By 2 November, this general expanse of ice was replaced by very heavy concentrations (>75%) (Fig. 12). Even with the formation of very heavy concentrations (>75%) of shorefast ice on 2 November, a wide nearshore band of open water still extended east-west across arctic waters (Fig. 12). The open-water conditions during Fall 1993 generally provided for good observation of subsurface whales, although associated high sea states sometimes reduced the ability of observers to spot whales near the surface or at great distances from the transect centerline. Ice percent and sea state at each sighting of endangered whales are shown in Appendix B (Table B-1).

Cloud ceilings over portions of the study area were often lower than the target-survey altitude of 458 m; but flying conditions were considered favorable most of the time, permitting 41 flights in 58 days.

III

B. Survey Effort

Daily totals of kilometers and hours flown per survey flight are shown in Table 3. A total of 36,809 km of surveys were flown in 166.32 hours (Table 3) in the Beaufort Sea at an average speed of 221.3 km/hr. A total of 16,617 km of random-transect lines were flown in 74.18 hours (Table 3) at an average speed of 224.0 km/hr. These random transects constituted 45.1 percent of the total kilometers flown and 44.6 percent of the total flight hours. The number of flight hours over each survey block is shown in subsequent analyses.

Day-to-day flight tracks are shown in Appendix B. Survey-flight lines are summarized by semimonthly period in Figures 13 through 16.

During the first half of September, survey coverage was widely distributed between 140°W. and 157°W. longitudes, with some effort in each survey block (Fig. 13). There were 19.45 hours of random transects flown from a total of 51.20 flight hours during this period (Table 3), constituting 26.2 percent and 30.8 percent, respectively, of the total time spent in those effort categories.

During the second half of September, survey coverage was distributed between 141°W. and 156°W. longitudes, within 100 nautical miles (nm) of shore (Fig. 14). There were 18.07 hours of random transects flown from 36.73 total flight hours during this period (Table 3), constituting 24.4 percent and 22.1 percent, respectively, of the total time spent in those effort categories.

During the first half of October, survey coverage was distributed between 140°W. and 154°W. longitudes, mostly within 100 nm of shore (Fig. 15). There were 23.22 hours of random transects flown from 44.60 total flight hours during this period (Table 3), constituting 31.3 percent and 26.8 percent, respectively, of the total time spent in those effort categories.

From 16 through 28 October, flight effort was distributed between 140°W. and 157°W. longitudes, within 70 nm of shore (Fig. 16). There were 13.45 hours of random transects flown from 33.78 total flight hours during this period (Table 3), constituting 18.1 percent and 20.3 percent, respectively, of the total time spent in those effort categories.

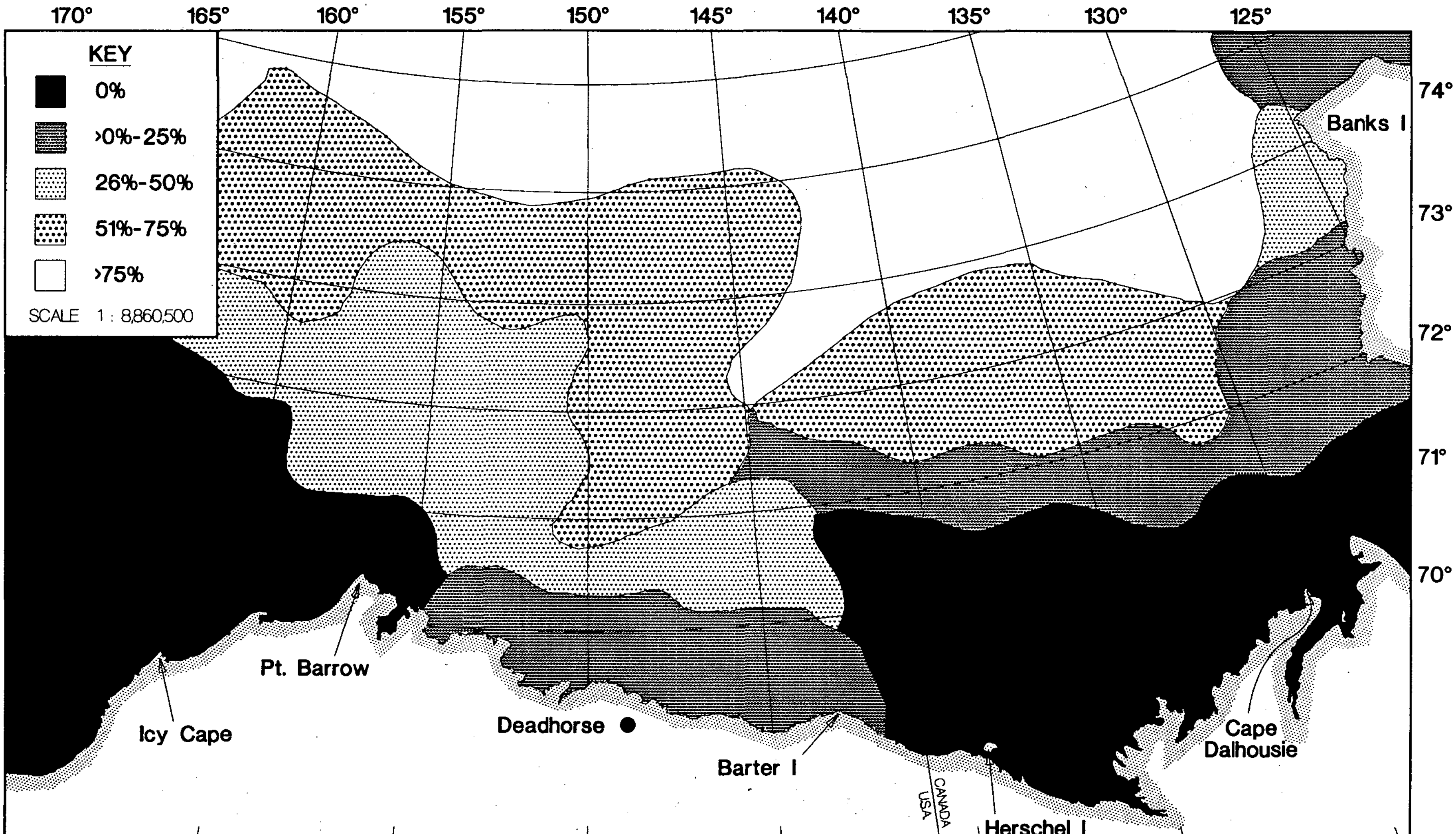

Figure 3. Map of Ice Concentrations in the Beaufort Sea, 31 August 1993

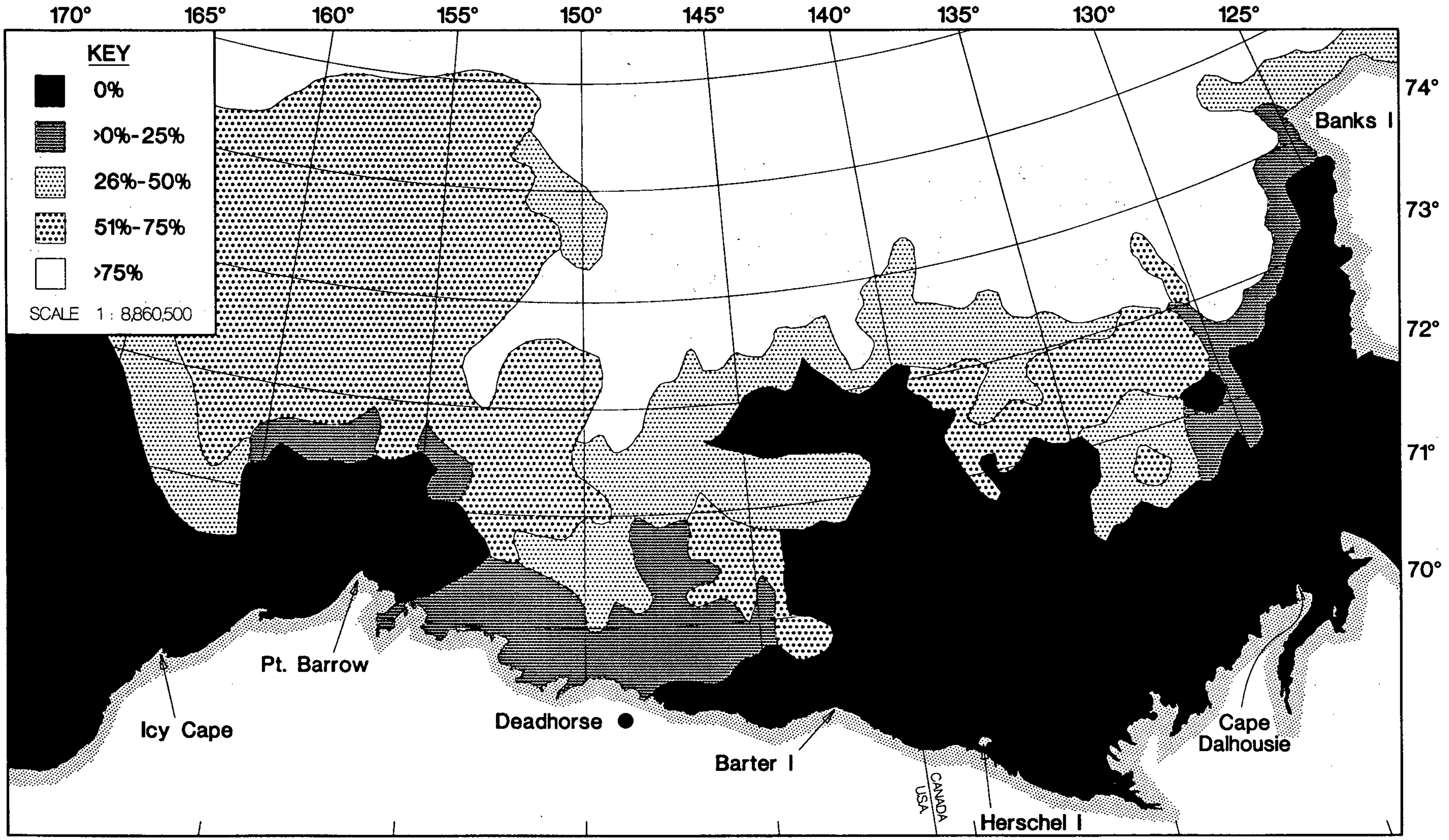

Figure 4. Map of Ice Concentrations in the Beaufort Sea, 7 September 1993

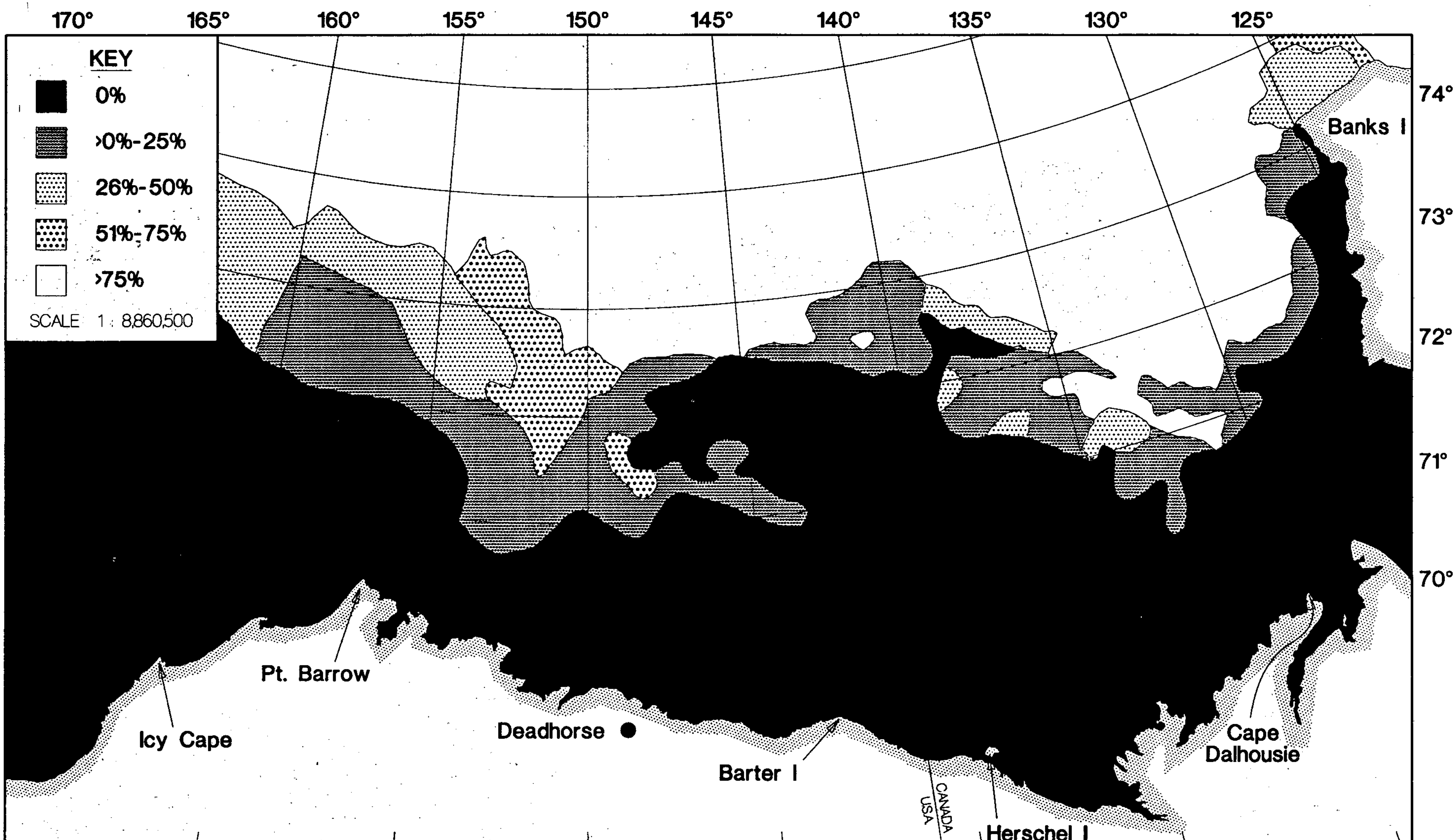

Figure 5. Map of Ice Concentrations in the Beaufort Sea, 14 September 1993

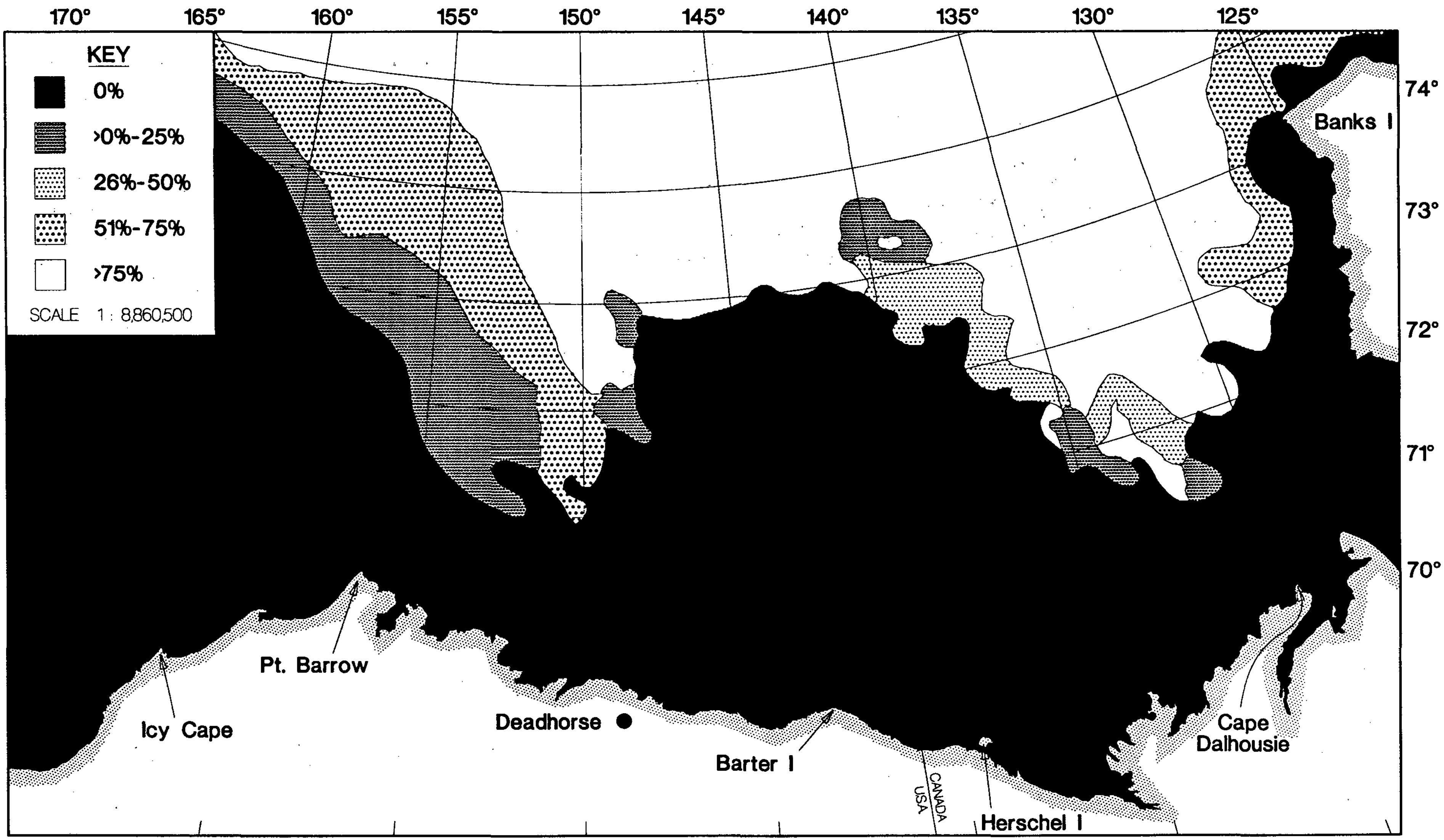

Figure 6. Map of Ice Concentrations in the Beaufort Sea, 21 September 1993

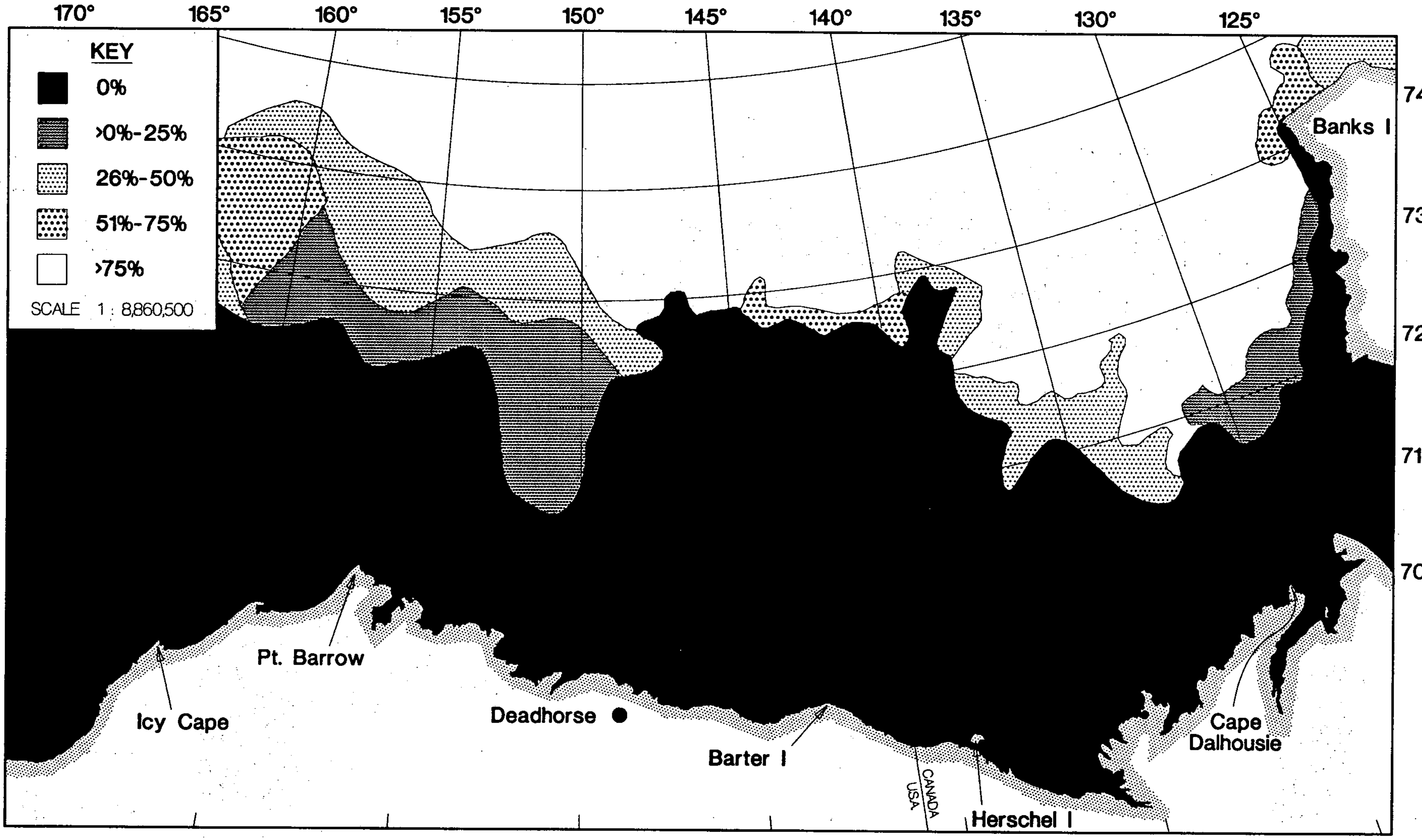

Figure 7. Map of Ice Concentrations in the Beaufort Sea, 28 September 1993

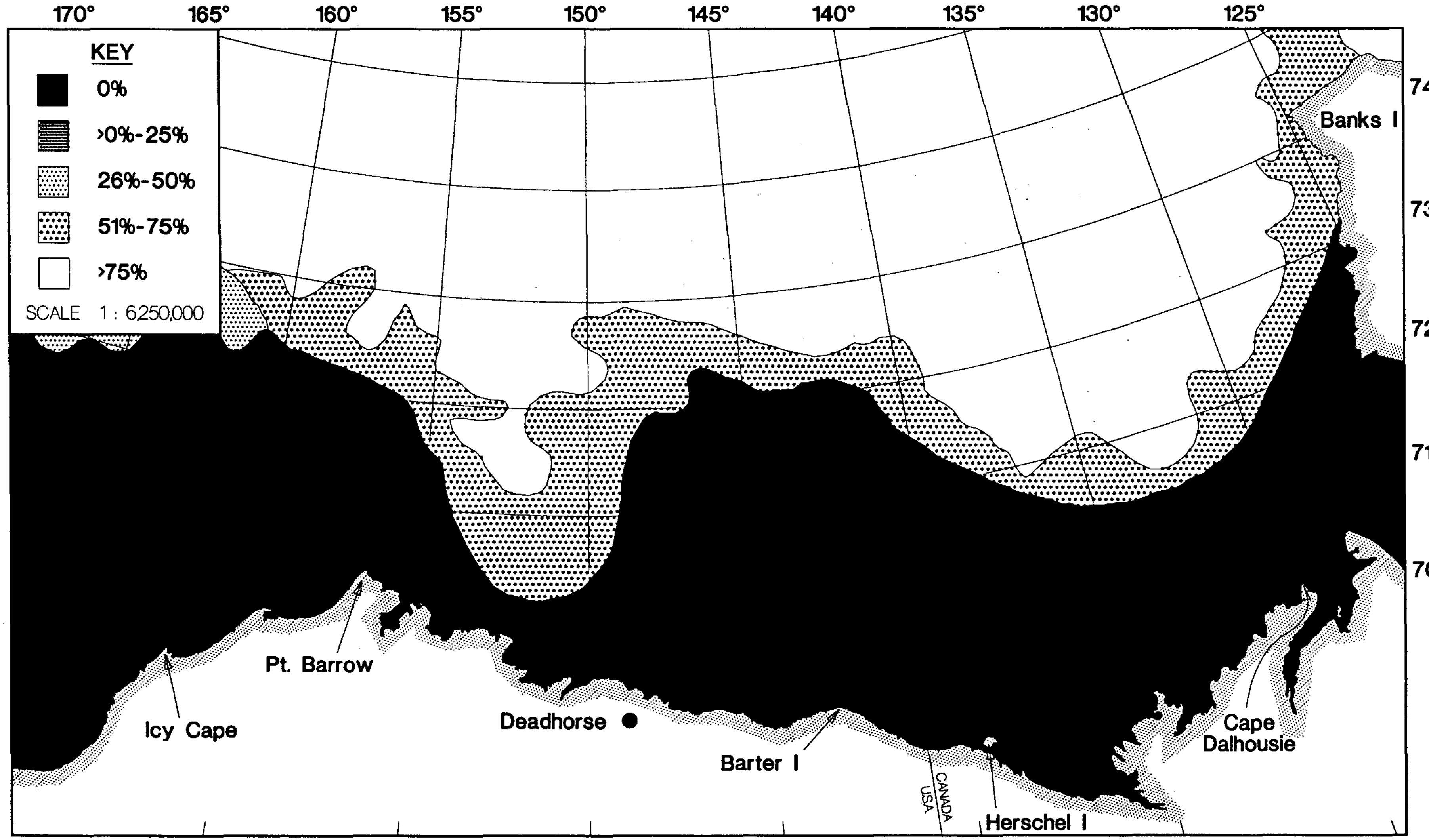

Figure 8. Map of Ice Concentrations in the Beaufort Sea, 5 October 1993

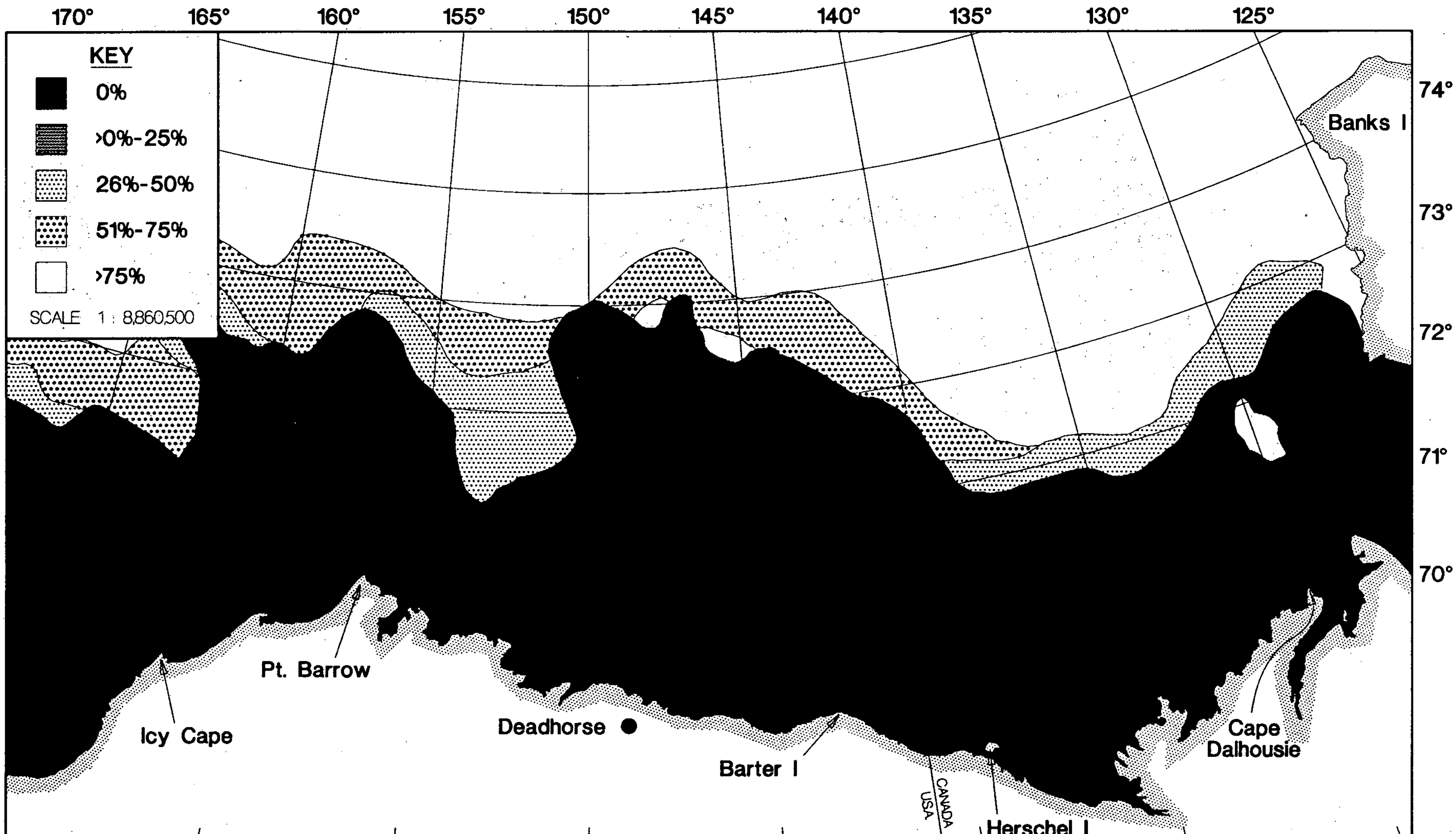

Figure 9. Map of Ice Concentrations in the Beaufort Sea, 12 October 1993

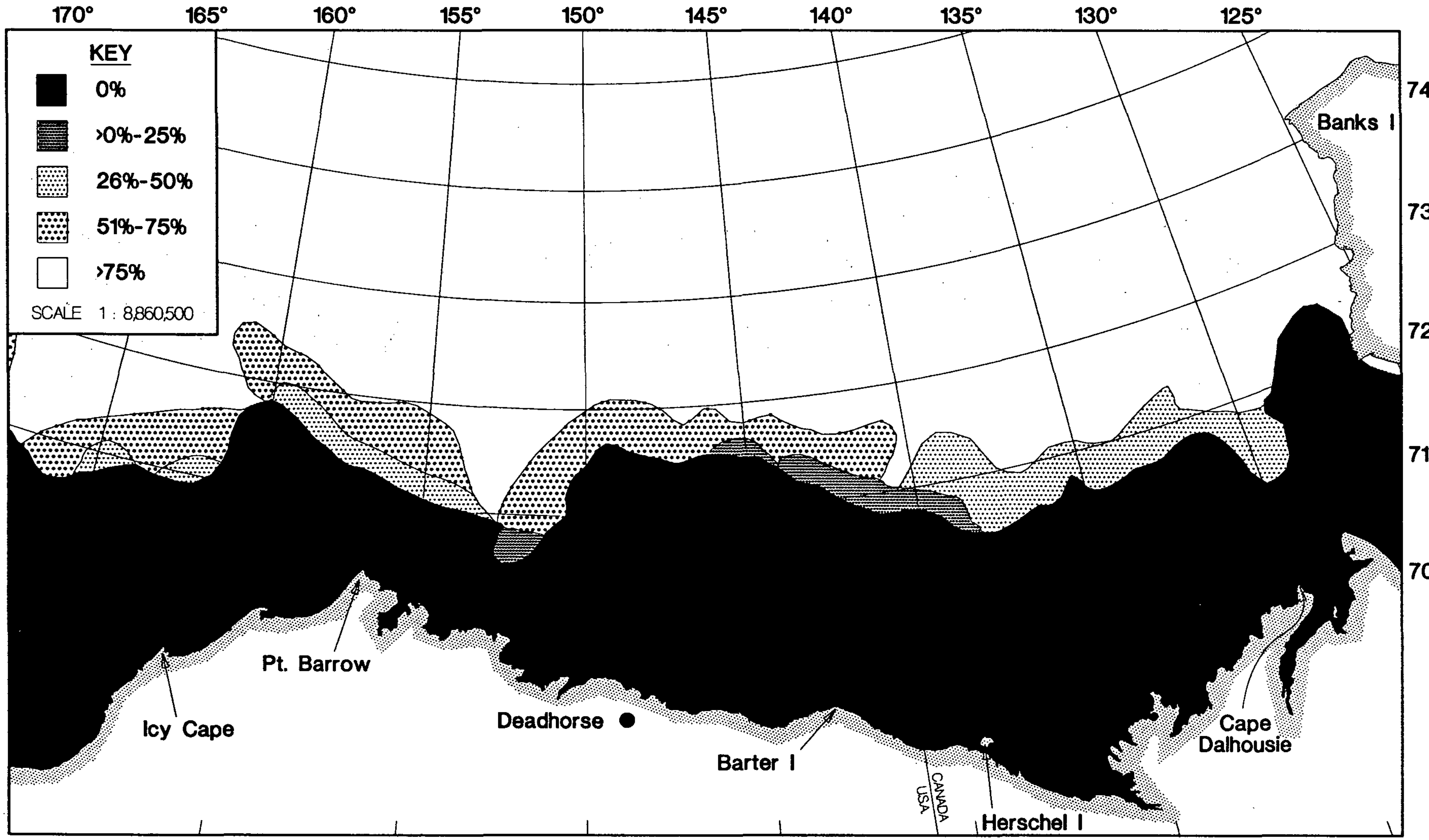

Figure 10. Map of Ice Concentrations in the Beaufort Sea, 19 October 1993

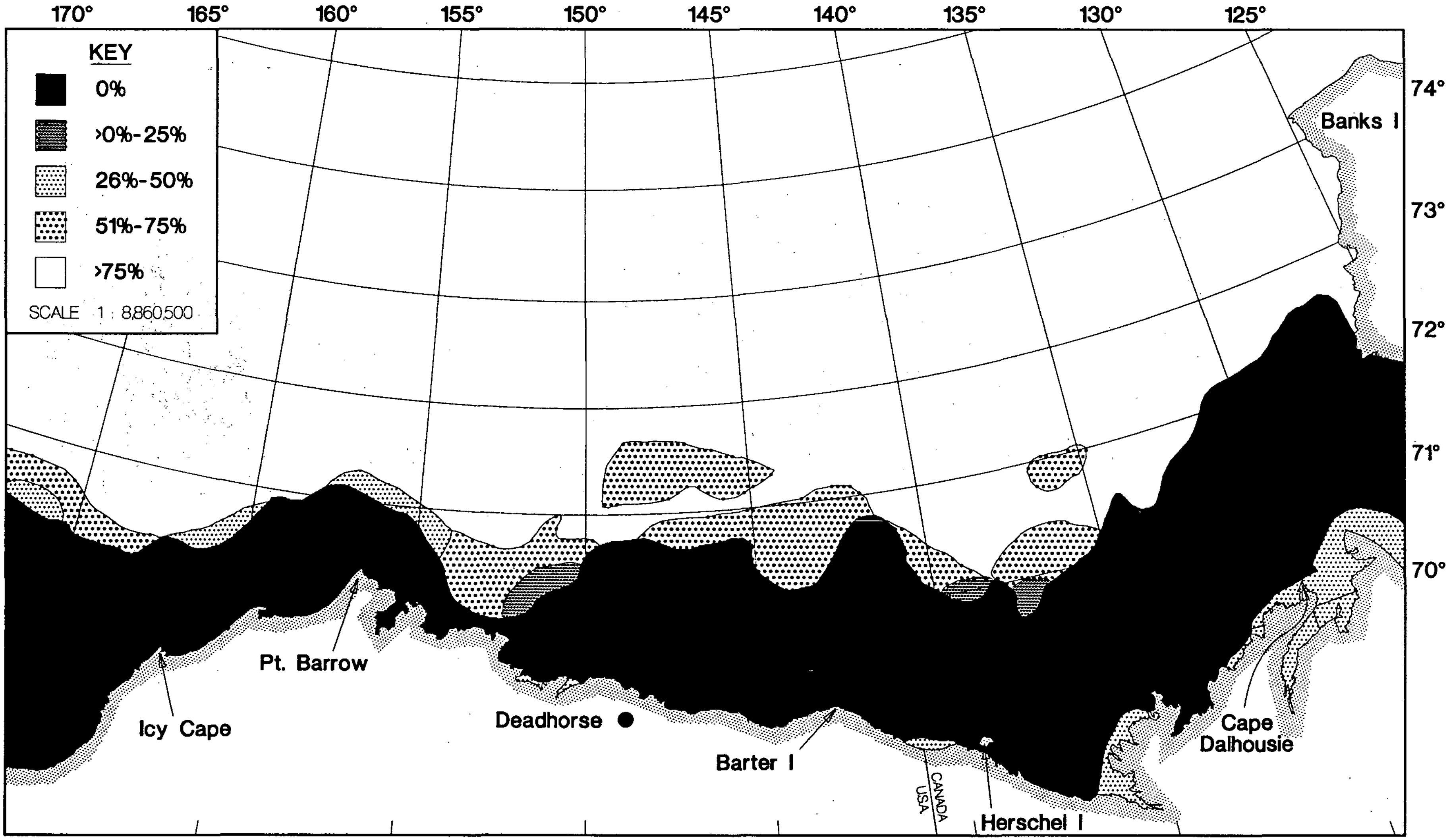

Figure 11. Map of Ice Concentrations in the Beaufort Sea, 26 October 1993

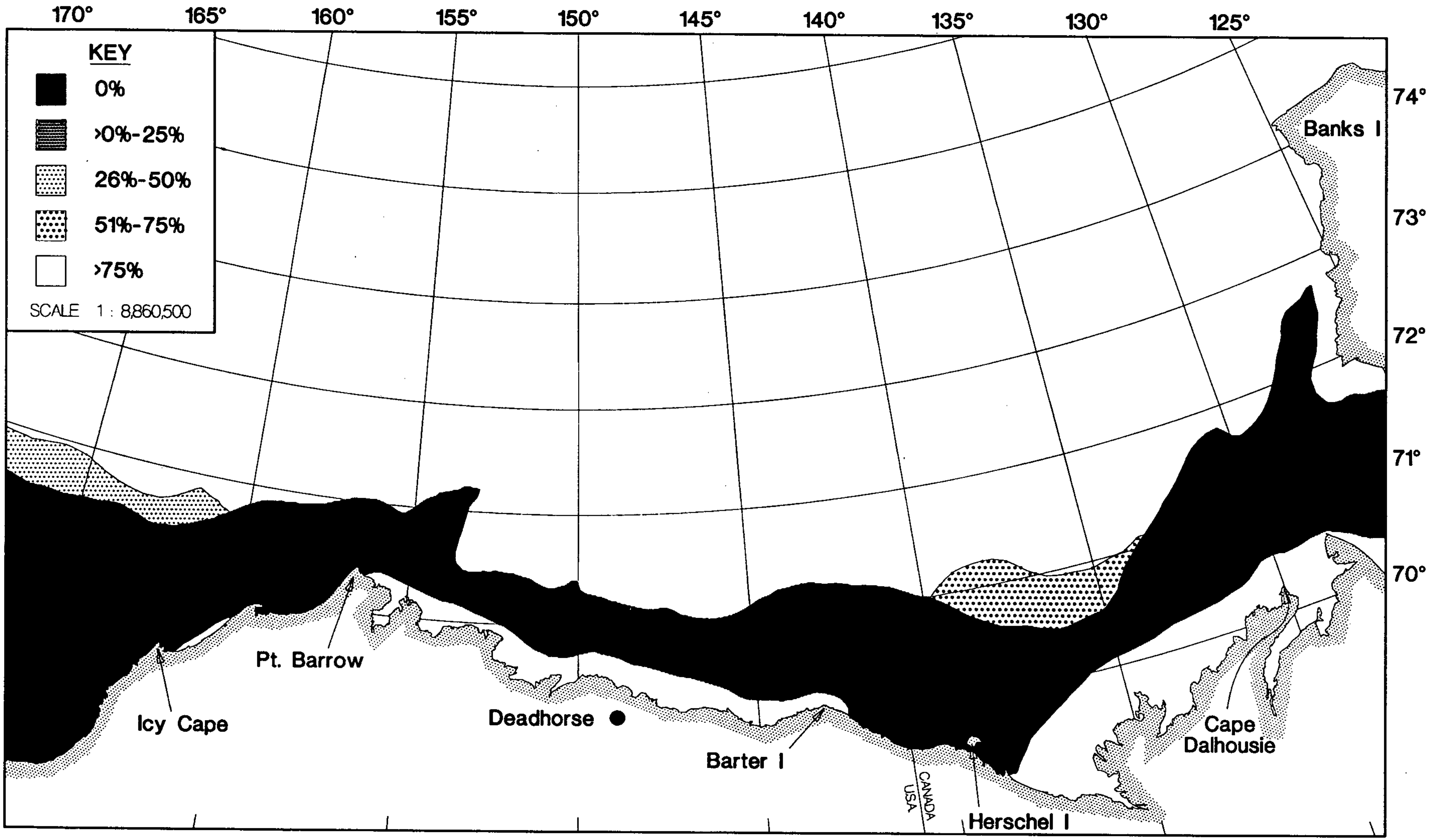

Figure 12. Map of Ice Concentrations in the Beaufort Sea, 2 November 1993

Table 3
Aerial-Survey Effort in the Beaufort Sea, 1 September-28 October 1993, by Survey Flight

Day	Flight No.	Transect (km)	Connect (km)	Search (km)	Total (km)	Transect Time (hr)	Total Survey Time (hr)
1 Sep	1	544	103	679	1,326	2.58	6.68
2 Sep	2	0	0	610	610	0.00	2.63
4 Sep	3	419	98	777	1,294	1.90	6.68
5 Sep	4	807	148	608	1,563	3.58	7.17
7 Sep	5	0	0	435	435	0.00	1.75
8 Sep	6	223	34	669	926	1.03	4.07
9 Sep	7	284	78	358	720	1.28	3.25
10 Sep	8	190	0	339	529	0.85	2.37
11 Sep	9	555	6	478	1,039	2.57	4.85
12 Sep	10	592	40	557	1,189	2.83	5.77
14 Sep	11	0	0	120	120	0.00	0.48
15 Sep	12	672	65	551	1,288	2.82	5.50
16 Sep	13	27	0	514	541	0.12	2.23
19 Sep	14	949	132	187	1,268	4.33	5.77
20 Sep	15	781	131	392	1,304	3.38	6.18
22 Sep	16	0	0	626	626	0.00	2.88
24 Sep	17	876	105	504	1,485	4.18	7.28
25 Sep	18	0	0	544	544	0.00	2.27
28 Sep	19	198	28	317	543	0.90	2.63
29 Sep	20	1,136	142	243	1,521	5.15	7.00
30 Sep	21	0	0	78	78	0.00	0.48
2 Oct	22	44	0	412	456	0.18	1.98
3 Oct	23	92	0	806	898	0.40	3.82
4 Oct	24	19	0	152	171	0.08	0.73
5 Oct	25	959	140	530	1,629	4.28	6.98
6 Oct	26	100	0	579	679	0.38	2.87
7 Oct	27	980	199	312	1,491	3.97	6.03
8 Oct	28	962	233	385	1,580	4.00	6.57
10 Oct	29	1,140	246	243	1,629	4.77	6.85
13 Oct	30	1,139	219	213	1,571	5.15	7.10
14 Oct	31	0	0	371	371	0.00	1.67
16 Oct	32	563	192	455	1,210	2.65	5.67
18 Oct	33	0	0	122	122	0.00	0.50
19 Oct	34	357	67	646	1,070	1.67	4.83
20 Oct	35	537	81	624	1,242	2.47	5.43
21 Oct	36	417	59	102	578	1.85	2.53
22 Oct	37	450	71	222	743	2.03	3.35
24 Oct	38	0	0	166	166	0.00	0.68
26 Oct	39	47	0	773	820	0.17	3.90
27 Oct	40	558	60	601	1,219	2.62	5.80
28 Oct	41	0	0	215	215	0.00	1.08

Table 3
Aerial-Survey Effort in the Beaufort Sea, 1 September-28 October 1993, by Survey Flight
(Continued)

Semimonthly Period	Transect (km)	Connect (km)	Search (km)	Total (km)	Transect Time (hr)	Total Survey Time (hr)
1-15 Sep	4,286	572	6,181	11,039	19.45	51.20
16-30 Sep	3,967	538	3,405	7,910	18.07	36.73
1-15 Oct	5,435	1,037	4,003	10,475	23.22	44.60
16-28 Oct	2,929	530	3,926	7,385	13.45	33.78
TOTAL	16,617	2,677	17,515	36,809	74.18	166.32

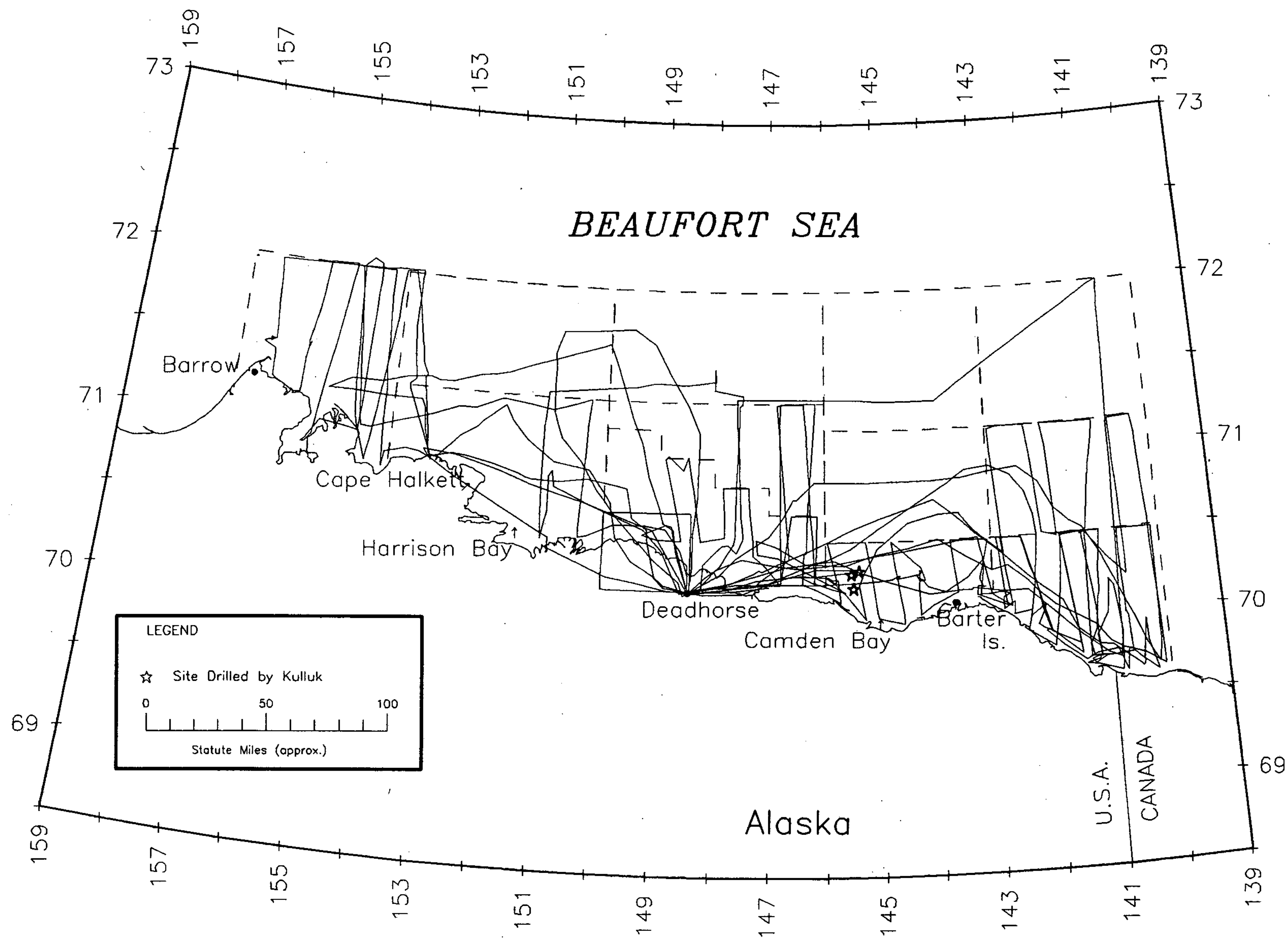

Figure 13. Combined Flight Tracks, 1-15 September 1993

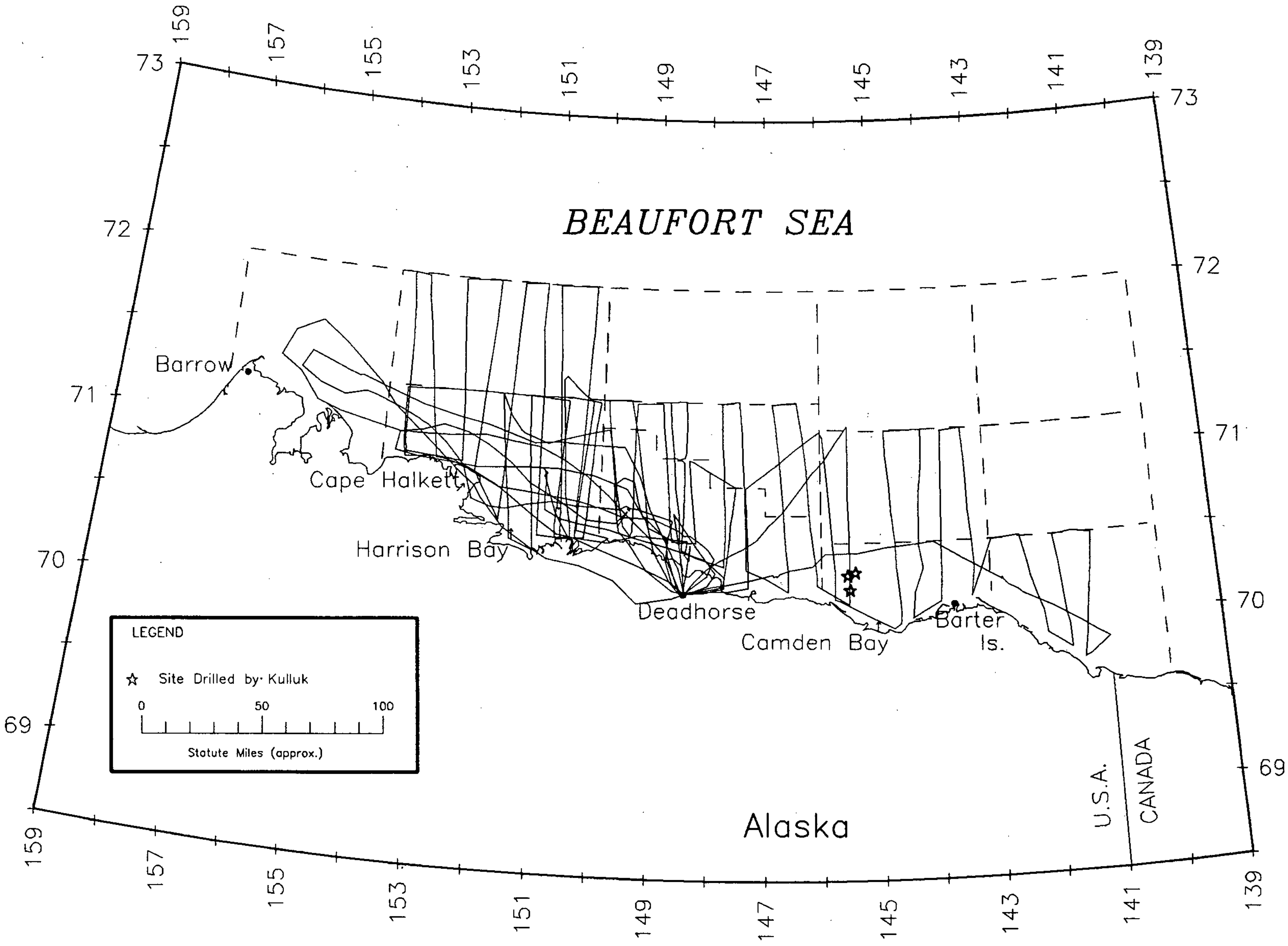

Figure 14. Combined Flight Tracks, 16-30 September 1993

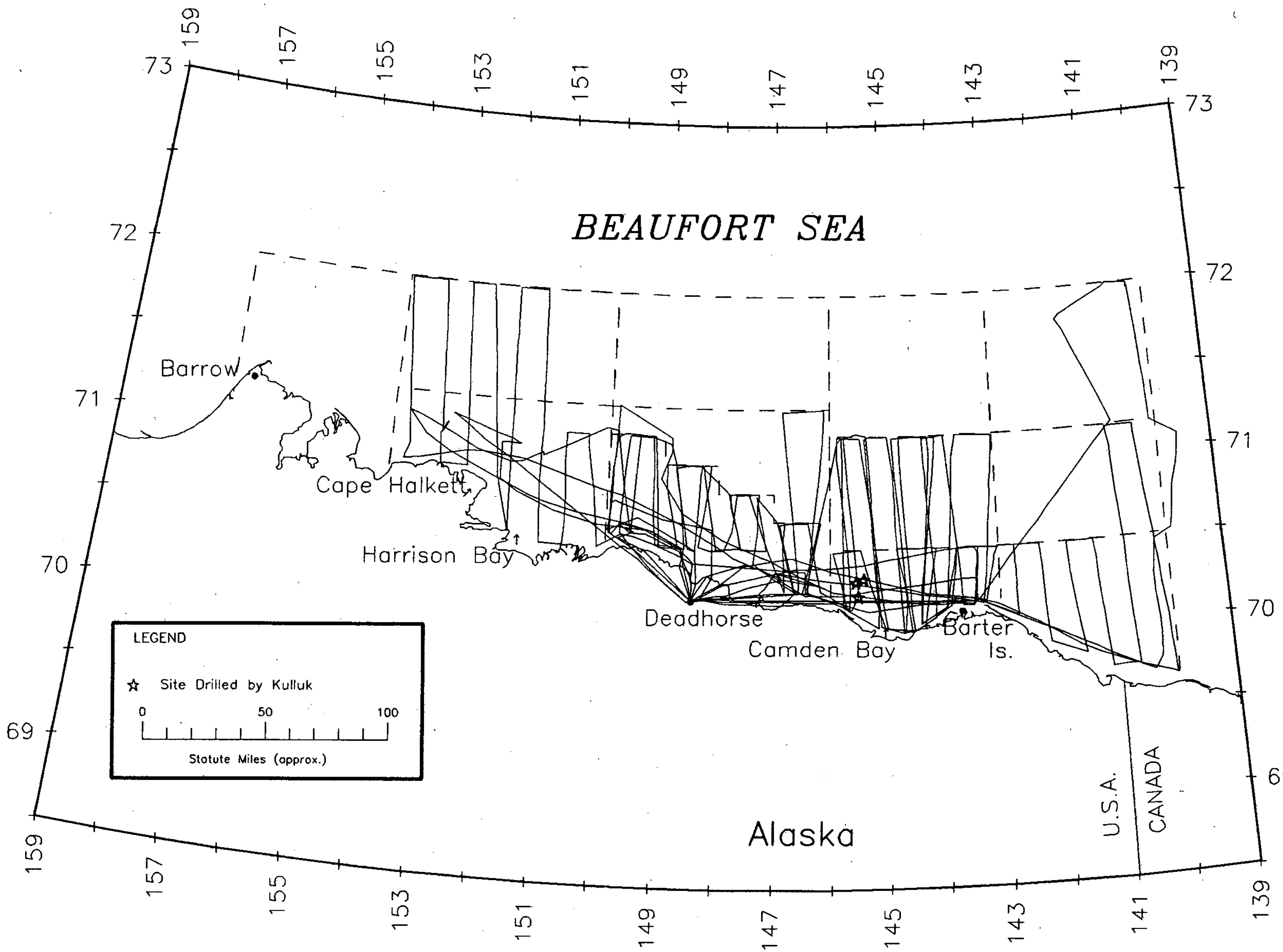

Figure 15. Combined Flight Tracks, 1-15 October 1993

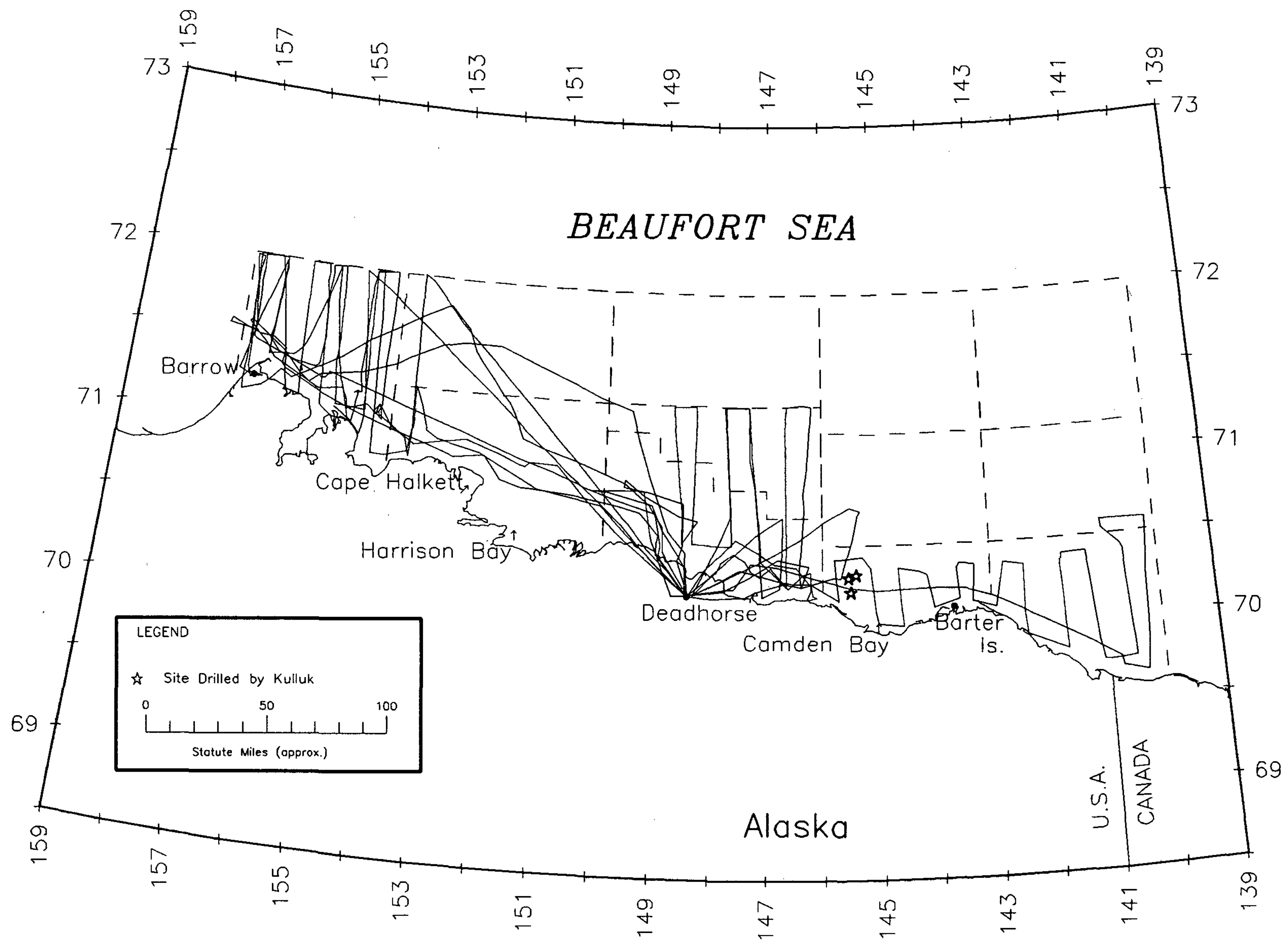

Figure 16. Combined Flight Tracks, 16-28 October 1993

C. Bowhead Whale (*Balaena mysticetus*) Observations

1. Distribution: Two hundred thirty-five sightings were made for a total of 353 bowhead whales observed during Fall-1993 surveys in the study area (Table 4 and Figs. 17-21), not counting repeat sightings. Four of these whales were identified as calves (Appendix B: Table B-1), resulting in a seasonal calf ratio (number calves/total whales) of 0.01. Daily sightings are shown on individual maps in Appendix B. A semi-monthly analysis follows.

During the first half of September, 58 sightings were made for a total of 86 bowheads (Table 4), with sightings from 140°42.0´W. to 156°33.9´W. longitudes (Appendix B: Table B-1), based on survey coverage between 140°W. and 157°W. longitudes (Fig. 13). Most of the whale pods were east of Deadhorse, Alaska, with 8 pods near Barrow, Alaska; all pods were within 30 nm north of the shoreline (Fig. 17). The first bowhead in the Alaskan Beaufort Sea was sighted on 1 September at 69°52.4´N. latitude, 141°45.1´W. longitude (Appendix B: Table B-1). Pod sizes ranged from 1 to 5 whales (Appendix B: Table B-1), with a mean of 1.48 (SD = 0.90, n = 58). Only one bowhead whale calf was observed during this period, at 69°59.5´N., 141°53.1´W on 8 September (Appendix B: Table B-1).

During the second half of September, 79 sightings were made for a total of 131 bowheads (Table 4), with sightings from 141°19.6´W. to 154°33.8´W. longitudes (Appendix B; Table B-1), based on survey coverage between 141°W. and 156°W. longitudes (Fig. 14). The whale pods were fairly evenly distributed east to west over the area surveyed, within 45 nm north of the shoreline (Fig. 18). Pod sizes ranged from 1 to 23 whales (Appendix B: Table B-1), with a mean of 1.66 (SD = 2.74, n = 79). One large pod of 11 bowhead whales was observed near the east side of Harrison Bay, just north of Oliktok Point, on 20 September; another large pod of 23 whales was observed slightly east of this same location on 29 September. Only one bowhead whale calf was observed during this period, at 70°58.9´N., 148°17.8´W. on 20 September (Appendix B: Table B-1).

During the first half of October, 62 sightings were made for a total of 79 bowheads (Table 4), with sightings from 142°42.1´W. to 153°40.5´W. longitudes (Appendix B: Table B-1), based on survey coverage between 140°W. and 154°W. longitudes (Fig. 15). The whale pods were fairly evenly distributed east-to-west over the area surveyed, within 50 nm north of the shoreline (Fig. 19). Pod sizes ranged from 1 to 3 whales (Appendix B: Table B-1), with a mean of 1.27 (SD = 0.55, n = 62). A total of two bowhead whale calves were observed during this period, one at 70°30.2´N., 144°19.8´W. on 8 October and one at 70°52.7´N., 148°10.7´W. on 10 October (Appendix B: Table B-1).

From 16 through 28 October, 36 sightings were made for a total of 57 bowheads (Table 4), with sightings from 143°16.8´W. to 156°47.7´W. longitudes (Appendix B: Table B-1), based on survey coverage between 140°W. and 157°W. longitudes (Fig. 16). All but two of the whale pods were west of 152°40.7´W., within 25 nm north of the shoreline (Fig. 20). Pod sizes ranged from 1 to 5 whales (Appendix B: Table B-1), with a mean of 1.58 (SD = 1.11, n = 36). No bowhead whale calves were observed during this period (Appendix B: Table B-1). The last pod of bowheads seen in the primary study area (east of 157°W. longitude) occurred on 27 October at 71°08.6´N. latitude, 154°14.3´W. longitude (Appendix B: Table B-1).

2. Migration Timing: The day-to-day timing of the bowhead whale migration was calculated over the entire study area (Table 5 and Fig. 22) as a daily sighting rate, or sightings per unit effort (SPUE), and an index of relative abundance, or whales per unit effort (WPUE).

Of the 235 sightings of bowhead whales observed, Table 5 shows that the first bowhead whales were sighted on 1 September. The data for daily sighting rates show a peak of 5.48 SPUE on 4 October. The last sighting of a bowhead was made on 27 October, followed by 1 flight in which no bowhead whales were sighted (Table 5 and Fig. 22).

Of the 353 bowhead whales counted during this period, the data for daily relative abundance (WPUE) show that the midpoint (median) of the bowhead migration in Blocks 1 through 12 (when 50% of all sighted whales

Table 4
Summary of Marine Mammal Sightings, 1 September-28 October 1993, by Survey Flight
(number of sightings/number of animals)

Day	Flight No.	Bowhead Whale	Belukha Whale	Unident. Cetacean	Bearded Seal	Ringed Seal	Unident. Pinniped	Polar Bear	Pacific Walrus
1 Sep	1	10/14	0	0	5/5	3/6	1/1	1/3	0
2 Sep	2	0	0	0	0	0	1/10	0	0
4 Sep	3	22/32	2/2	1/1	0	8/17	0	0	0
5 Sep	4	0	0	0	0	2/2	0	0	0
7 Sep	5	0	0	0	0	0	0	0	0
8 Sep	6	5/12	1/2	0	0	1/20	0	0	0
9 Sep	7	10/12	0	0	0	1/2	0	0	0
10 Sep	8	0	0	0	0	0	0	0	0
11 Sep	9	0	1/1	0	1/3	22/219	2/2	1/1	2/3
12 Sep	10	8/13	3/3	1/1	0	2/5	1/6	1/1	0
14 Sep	11	0	0	0	0	0	0	0	0
15 Sep	12	3/3	0	0	0	25/95	1/1	0	0
16 Sep	13	0	0	0	0	0	0	0	0
19 Sep	14	10/10	0	0	2/3	10/24	0	0	0
20 Sep	15	20/33	1/1	0	0	4/10	0	0	0
22 Sep	16	2/2	0	0	0	0	0	0	0
24 Sep	17	18/22	0	0	0	0	2/2	0	0
25 Sep	18	0	0	0	0	0	0	0	0
28 Sep	19	6/8	2/2	0	0	0	0	0	0
29 Sep	20	23/56	14/67	0	0	0	0	0	0
30 Sep	21	0	0	0	0	0	0	0	0
2 Oct	22	1/1	0	0	0	0	0	0	0
3 Oct	23	7/9	0	0	0	0	0	0	0
4 Oct	24	4/4	0	0	0	0	0	0	0
5 Oct	25	14/21	3/3	0	0	0	0	0	0
6 Oct	26	1/1	0	0	0	0	0	0	0
7 Oct	27	6/8	3/8	0	0	4/5	3/3	0	0
8 Oct	28	16/19	0	0	1/1	1/1	0	0	0
10 Oct	29	6/7	0	0	1/1	0	1/1	0	0
13 Oct	30	6/7	2/55	0	0	1/1	0	0	0
14 Oct	31	1/2	0	0	0	0	0	0	0
16 Oct	32	1/1	0	0	0	0	0	0	0
18 Oct	33	0	0	0	0	0	0	0	0
19 Oct	34	5/7	3/3	0	0	0	0	0	0
20 Oct	35	23/34	2/2	0	0	1/1	0	0	0
21 Oct	36	0	0	0	0	1/1	0	0	0
22 Oct	37	1/1	0	0	0	0	0	0	0
24 Oct	38	0	0	0	0	0	0	0	0
26 Oct	39	4/8	0	0	0	0	0	0	0
27 Oct	40	2/6	0	0	0	1/1	0	0	0
28 Oct	41	0	0	0	0	0	0	0	0

Table 4
Summary of Marine Mammal Sightings, 1 September-28 October 1993, by Survey Flight
(number of sightings/number of animals)
(Continued)

Day	Bowhead Whale	Belukha Whale	Unident. Cetacean	Bearded Seal	Ringed Seal	Unident. Pinniped	Polar Bear	Pacific Walrus
Total Semimonthly Sightings								
1-15 Sep	58/86	7/8	2/2	6/8	64/366	6/20	3/5	2/3
16-30 Sep	79/131	17/70	0	2/3	14/34	2/2	0	0
1-15 Oct	62/79	8/66	0	2/2	6/7	4/4	0	0
16-28 Oct	36/57	5/5	0	0	3/3	0	0	0
TOTAL	235/353	37/149	2/2	10/13	87/410	12/26	3/5	2/3

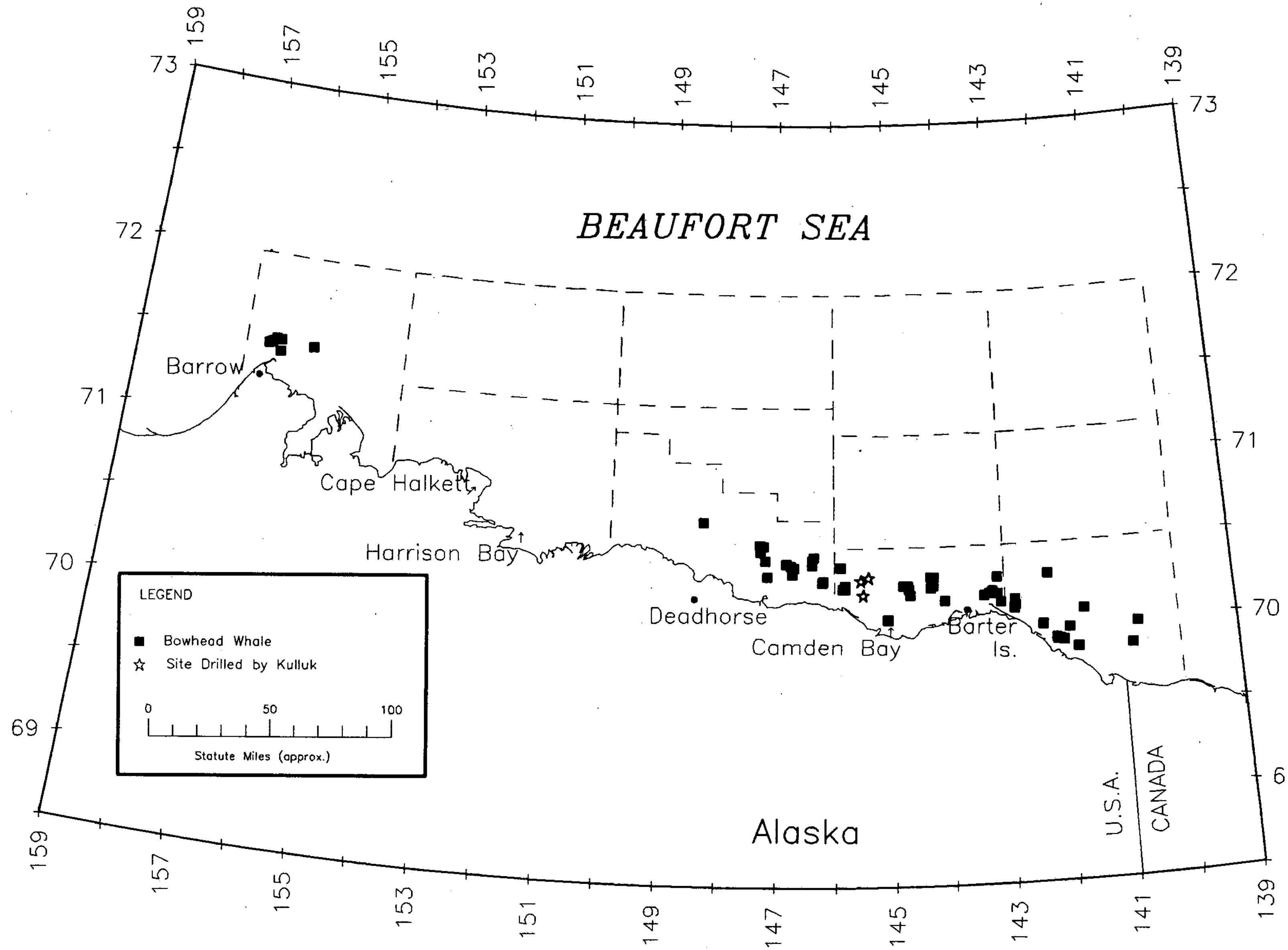

Figure 17. Map of Bowhead Whale Sightings, 1-15 September 1993

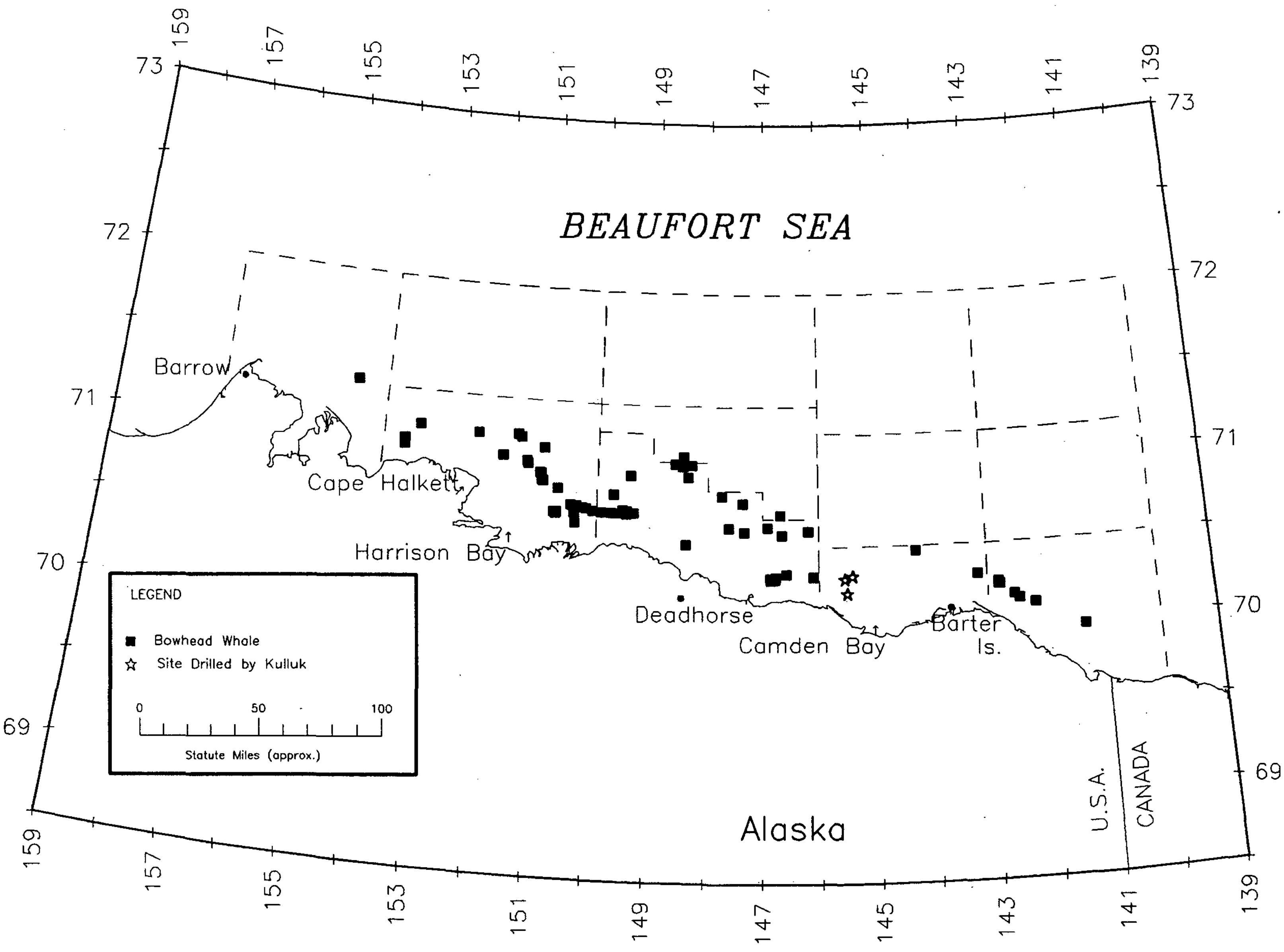

Figure 18. Map of Bowhead Whale Sightings, 16-30 September 1993

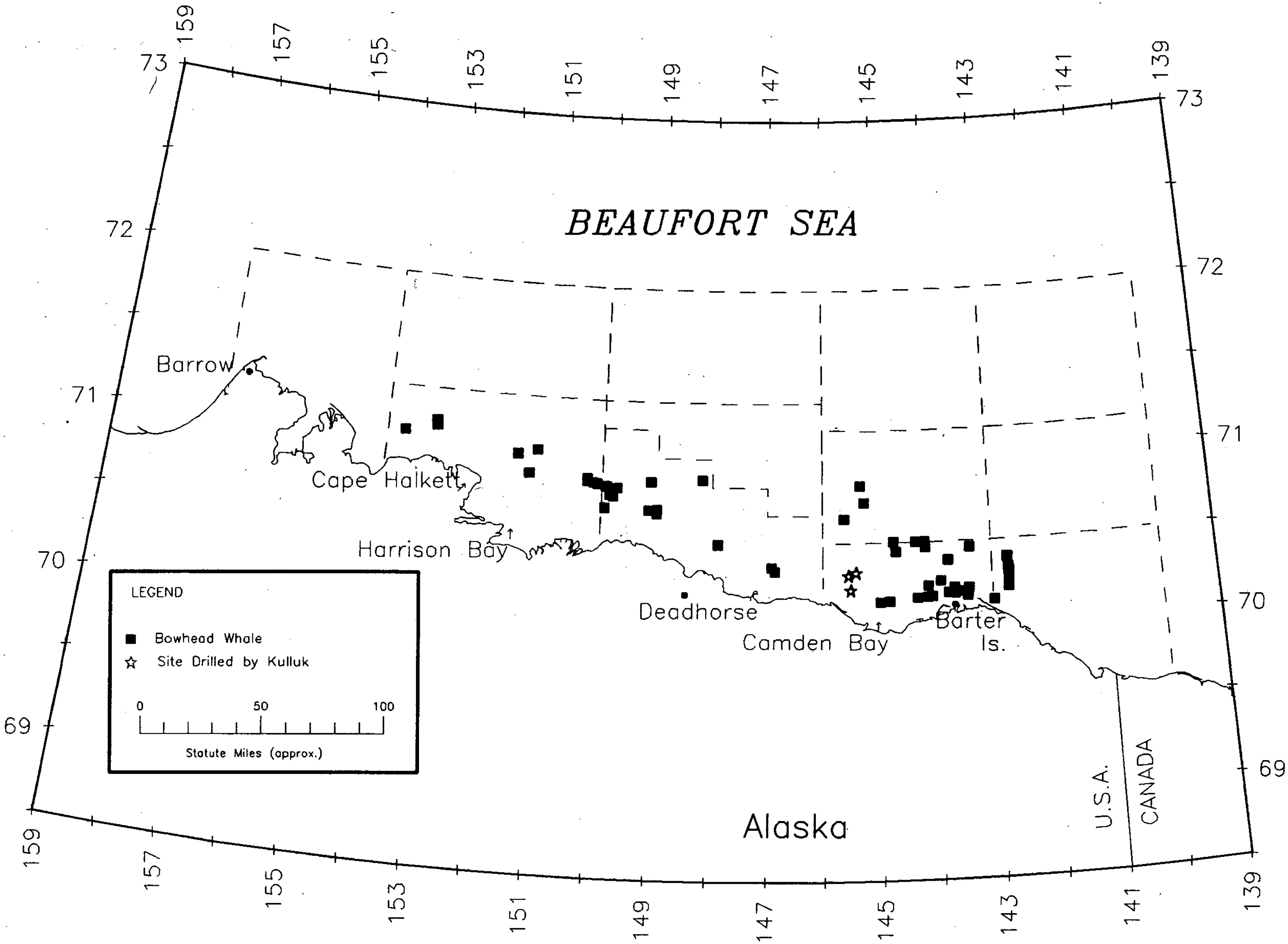

Figure 19. Map of Bowhead Whale Sightings, 1-15 October 1993

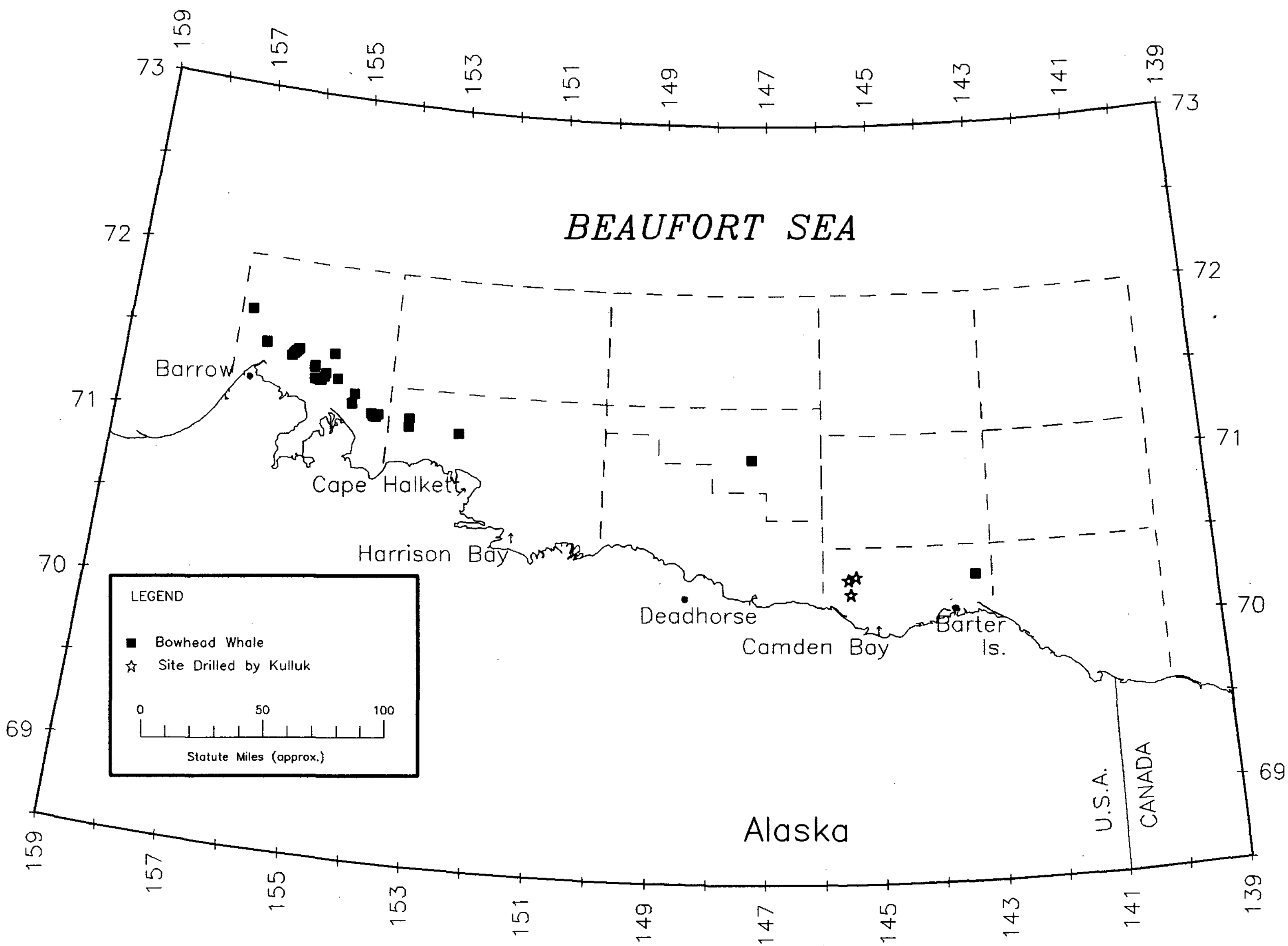

Figure 20. Map of Bowhead Whale Sightings, 16-28 October 1993

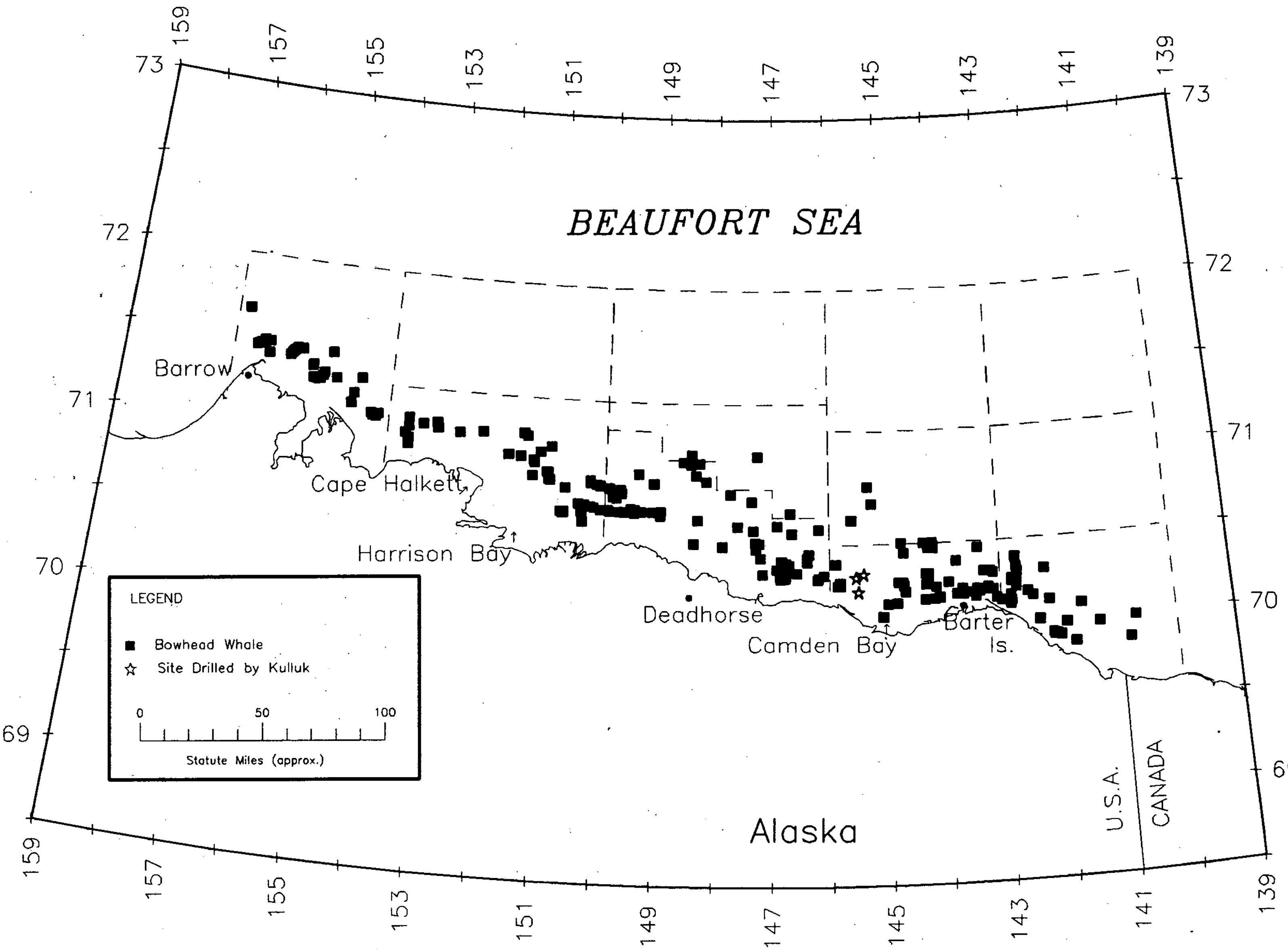

Figure 21. Map of Bowhead Whale Sightings, Fall 1993

Table 5
Number of Sightings and Total Bowhead Whales Observed per Hour,
1 September-28 October 1993, by Flight Day

Day	No. of Sightings	No. of Whales	Total Survey Time (hr)	Sightings/ Hour (SPUE)	Whales/ Hour (WPUE)
1 Sep	10	14	6.68	1.50	2.10
2 Sep	0	0	2.63	0.00	0.00
4 Sep	22	32	6.68	3.29	4.79
5 Sep	0	0	7.17	0.00	0.00
7 Sep	0	0	1.75	0.00	0.00
8 Sep	5	12	4.07	1.29	2.95
9 Sep	10	12	3.25	3.08	3.69
10 Sep	0	0	2.37	0.00	0.00
11 Sep	0	0	4.85	0.00	0.00
12 Sep	8	13	5.77	1.39	2.25
14 Sep	0	0	0.48	0.00	0.00
15 Sep	3	3	5.50	0.55	0.55
16 Sep	0	0	2.23	0.00	0.00
19 Sep	10	10	5.77	1.73	1.73
20 Sep	20	33	6.18	3.24	5.34
22 Sep	2	2	2.88	0.69	0.69
24 Sep	18	22	7.28	2.47	3.02
25 Sep	0	0	2.27	0.00	0.00
28 Sep	6	8	2.63	2.28	3.04
29 Sep	23	56	7.00	3.29	8.00
30 Sep	0	0	0.48	0.00	0.00
2 Oct	1	1	1.98	0.51	0.51
3 Oct	7	9	3.82	1.83	2.36
4 Oct	4	4	0.73	5.48	5.48
5 Oct	14	21	6.98	2.01	3.01
6 Oct	1	1	2.87	0.35	0.35
7 Oct	6	8	6.03	1.00	1.33
8 Oct	16	19	6.57	2.44	2.89
10 Oct	6	7	6.85	0.88	1.02
13 Oct	6	7	7.10	0.85	0.99
14 Oct	1	2	1.67	0.60	1.20
16 Oct	1	1	5.67	0.18	0.18
18 Oct	0	0	0.50	0.00	0.00
19 Oct	5	7	4.83	1.04	1.45
20 Oct	23	34	5.43	4.24	6.26
21 Oct	0	0	2.53	0.00	0.00
22 Oct	1	1	3.35	0.30	0.30
24 Oct	0	0	0.68	0.00	0.00
26 Oct	4	8	3.90	1.03	2.05
27 Oct	2	6	5.80	0.34	1.03
28 Oct	0	0	1.08	0.00	0.00
TOTAL	235	353	166.32	1.41	2.12

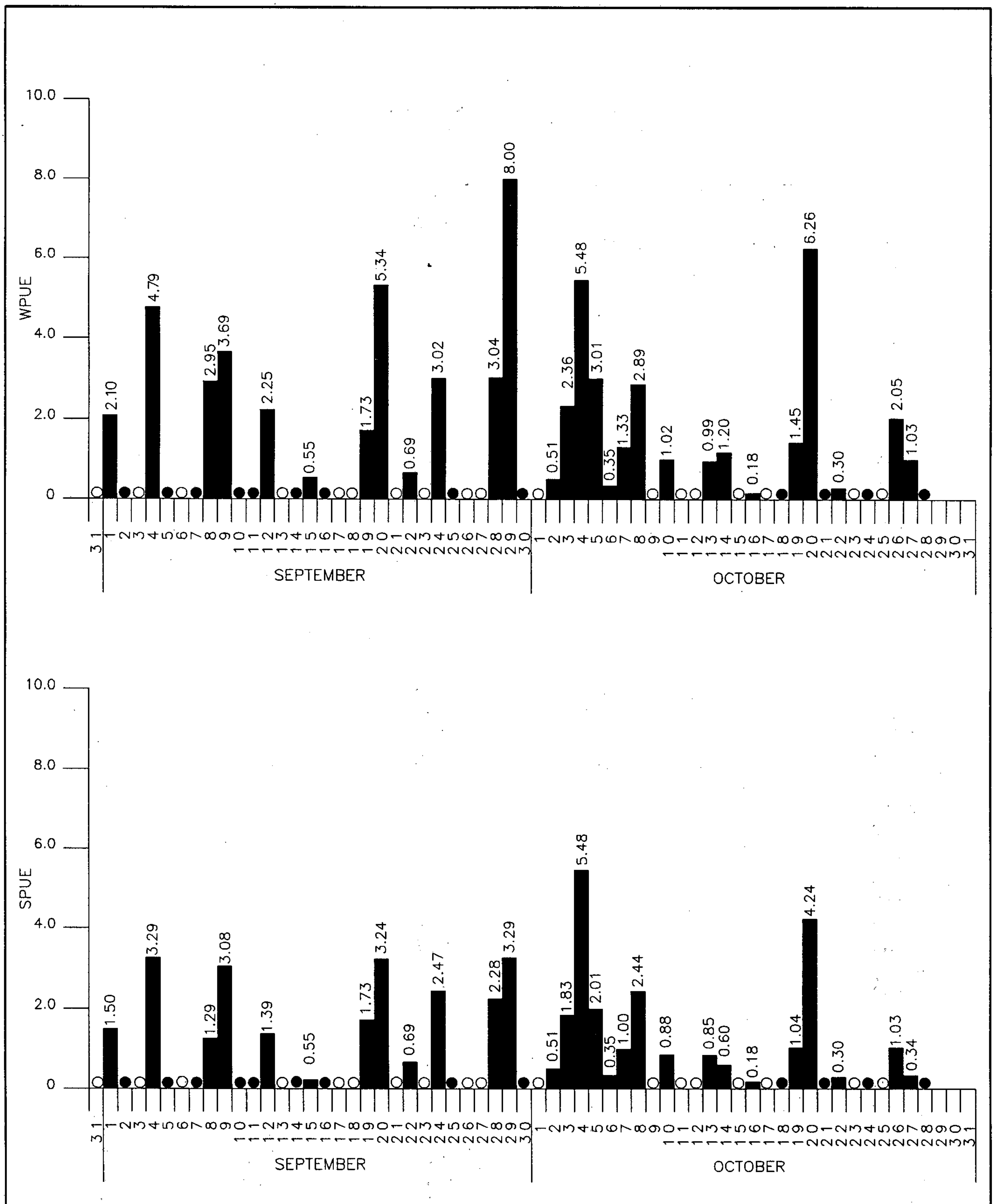

Figure 22. Daily Relative Abundance (WPUE) and Sighting Rate (SPUE) of Bowhead Whales, 1 September-28 October 1993

(Solid circles indicate days when flights were made during which no bowheads were observed. Open circles indicate days when no flight was made.)

had been recorded) occurred on 29 September (Table 5). The peak relative abundance (mode) of 8.00 WPUE also occurred on 29 September (Table 5 and Fig. 22).

The most prominent difference in pattern between the graph for relative abundance and that for sighting rate occurred on 29 September (Fig. 22), due to a large pod of 23 whales on that day (Appendix B: Table B-1).

3. Relative Abundance by Survey Blocks: The relative abundance of bowhead whales in each Beaufort Sea survey block (Fig. 1), in Chukchi Sea survey blocks, in Canadian waters east of 140°W. longitude, and in Alaskan waters outside of historically monitored survey blocks, was calculated in Table 6. Over the field season (1 September-28 October), there were 5 survey blocks in which ≥15.00 hr of survey effort were made. Of these coastal blocks (Blocks 1, 3, 4, 5, and 12), Block 12 (3.45 WPUE) had the greatest relative abundance, followed by Block 4 (3.07 WPUE), Block 3 (2.57 WPUE), Block 1 (2.56 WPUE), and Block 5 (2.13 WPUE) (Table 6).

During the first half of September, there were 5 blocks in which ≥4.00 hr of survey effort were made. Of these coastal blocks (Blocks 1, 3, 4, 5, and 12), Block 4 (5.33 WPUE) had the greatest relative abundance, followed by Block 12 (2.23 WPUE), Block 1 (2.09 WPUE), Block 5 (1.76 WPUE), and Block 3, for which no whales were observed. No bowheads were observed during a total of 12.84 hr of survey effort in the remaining blocks (Blocks 2, 6, 7, 8, 9, 10, and 11) of the primary study area or adjacent waters (Table 6).

During the second half of September, there were 2 blocks in which ≥4.00 hr of survey effort were made. Of these coastal blocks (Blocks 1 and 3), Block 1 (6.81 WPUE) had the greatest relative abundance, followed by Block 3 (4.25 WPUE). Although only 1.95 hr of survey effort were made in Block 5, it was notable that 8 whales were observed in this coastal block, for a high relative abundance (4.10 WPUE). Three bowheads were observed during a total of 12.29 hr of survey effort in the remaining blocks (Blocks 2, 4, 6, 7, 8, 9, 10, 11, and 12) of the primary study area or adjacent waters (Table 6).

During the first half of October, there were 4 blocks in which ≥4.00 hr of survey effort were made. Of these coastal and offshore blocks (Blocks 1, 3, 4, and 6), coastal Block 4 (2.74 WPUE) had the greatest relative abundance, followed by Block 3 (2.44 WPUE), Block 1 (1.30 WPUE), and offshore Block 6 (1.28 WPUE). Although only 3.60 hr of survey effort were made in coastal Block 5, it was notable that 14 whales were observed, for a high relative abundance (3.89 WPUE). No bowheads were observed during a total of 6.4 hr of survey effort in remaining blocks (Blocks 2, 7, 8, 9, 10, and 11) of the primary study area or adjacent waters (Table 6).

From 16 through 28 October, there were 3 blocks in which ≥4.00 hr of survey effort were made. Of these coastal blocks (Blocks 1, 3, and 12), Block 12 (4.40 WPUE) had the greatest relative abundance, followed by Block 3 (0.88 WPUE), and Block 1 (0.13 WPUE). Only one bowhead was observed during a total of 10.02 hr of survey effort in remaining blocks (Blocks 2, 4, 5, 6, 7, 8, 9, 10, and 11) of the primary study area or adjacent waters (Table 6).

4. Habitat Associations: Of 353 bowhead whales sighted during Fall 1993, 326 (92%) were in shallow water (0-50 m deep), 26 (7%) were in waters of transitional depth (51-200 m), and 1 (1%) was sighted in deeper water (>200 m) (Table 7). A fuller description of depth associated with the bowhead migration appears in the discussion on median-water-depth analysis in Section IV.B.

In addition to general ice coverage for arctic waters (Figs. 3-12), the percentage of ice cover visible from the aircraft at each bowhead sighting (Appendix B: Table B-1) was summarized (Table 8). Over the field season (1 September-28 October), bowheads were sighted in each concentration of ice cover shown on Table 8. Of 353 bowheads, 330 (93%) were sighted in open water (0-% sea ice), 12 (3%) in 41- through 50-percent ice, 10 (3%) in 1- through 5-percent ice, and 1 in 51- through 60-percent ice (Table 8). From 1 September-22 October, all bowheads sighted were associated with open water or ≤5-percent sea ice (Appendix B: Table B-1). It was not until 26 October that concentrations of ice greater than 5 percent were observed in association with bowhead sightings (Appendix B: Table B-1).

Table 6

Semimonthly Relative Abundance (WPUE) of Bowhead Whales (BH), by Survey Block, Fall 1993

Block	1-15 Sep			16-30 Sep			1-15 Oct			16-28 Oct			Total		
	Hr	BH	WPUE	Hr	BH	WPUE	Hr	BH	WPUE	Hr	BH	WPUE	Hr	BH	WPUE
1	10.03	21	2.09	9.54	65	6.81	13.85	18	1.30	7.63	1	0.13	41.05	105	2.56
2	2.29	0	0.00	2.47	0	0.00	1.41	0	0.00	2.31	0	0.00	8.48	0	0.00
3	5.18	0	0.00	12.95	55	4.25	6.16	15	2.44	4.52	4	0.88	28.82	74	2.57
4	6.00	32	5.33	2.35	2	0.85	9.12	25	2.74	2.07	1	0.48	19.55	60	3.07
5	11.34	20	1.76	1.95	8	4.10	3.60	14	3.89	2.80	0	0.00	19.70	42	2.13
6	1.95	0	0.00	2.35	0	0.00	5.46	7	1.28	0.18	0	0.00	9.93	7	0.70
7	3.50	0	0.00	0.16	0	0.00	1.16	0	0.00	0.24	0	0.00	5.06	0	0.00
8	0.80	0	0.00	[1]	[1]	[1]	1.17	0	0.00	[1]	[1]	[1]	1.97	0	0.00
9	0.47	0	0.00	0.03	0	0.00	0.09	0	0.00	[1]	[1]	[1]	0.59	0	0.00
10	1.28	0	0.00	0.17	0	0.00	0.01	0	0.00	0.07	0	0.00	1.53	0	0.00
11	1.94	0	0.00	3.32	0	0.00	2.21	0	0.00	2.23	0	0.00	9.70	0	0.00
12	5.82	13	2.23	1.44	1	0.69	[1]	[1]	[1]	11.60	51	4.40	18.86	65	3.45
13	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]	0.09	0	0.00	0.09	0	0.00
12N	0.52	0	0.00	[1]	[1]	[1]	[1]	[1]	[1]	0.02	0	0.00	0.54	0	0.00
Other Canadian Areas	[1]	[1]	[1]	[1]	[1]	[1]	0.35	0	0.00	[1]	[1]	[1]	0.35	0	0.00
Other Alaskan Areas	0.09	0	0.00	[1]	[1]	[1]	[1]	[1]	[1]	0.01	0	0.00	0.10	0	0.00
TOTAL	51.20	86	1.68	36.73	131	3.57	44.60	79	1.77	33.78	57	1.69	166.32	353	2.12

[1] No survey effort.

Table 7
Semimonthly Summary of Bowhead Whales Observed, by Water Depth at Sighting Location, Fall 1993

Water Depth	1-15 Sep No. (%)	16-30 Sep No. (%)	1-15 Oct No. (%)	16-28 Oct No. (%)	Total No. (%)
Shallow (0-50 m)	75 (87)	129 (98)	69 (88)	53 (93)	326 (92)
Transitional (51-200 m)	11 (13)	2 (2)	9 (11)	4 (7)	26 (7)
Deep (>200 m)	0	0	1 (1)	0	1 (1)
TOTAL	86 (100)	131 (100)	79 (100)	57 (100)	353 (100)

Table 8
Semimonthly Summary of Bowhead Whales Observed, by Percent Ice Cover Present at Sighting Location, Fall 1993

% Ice Cover	1-15 Sep No. (%)	16-30 Sep No. (%)	1-15 Oct No. (%)	16-28 Oct No. (%)	Total No. (%)
0	76 (88)	131 (100)	79 (100)	44 (77)	330 (93)
1-5	10 (12)	0	0	0	10 (3)
6-10	0	0	0	0	0
11-20	0	0	0	0	0
21-30	0	0	0	0	0
31-40	0	0	0	0	0
41-50	0	0	0	12 (21)	12 (3)
51-60	0	0	0	1 (2)	1 (1)
61-70	0	0	0	0	0
71-80	0	0	0	0	0
81-90	0	0	0	0	0
91-99	0	0	0	0	0
TOTAL	86 (100)	131 (100)	79 (100)	57 (100)	353 (100)

5. Behavior, Swim Direction, and Speed: Of 353 bowhead whales observed during Fall 1993, 232 (66%) were swimming (Table 9), i.e., moving forward in an apparently deliberate manner, when first sighted. Over the fall season, the greatest proportion (0.42) of directional movement was between west and northwest, with a significant ($p < 0.001$) mean heading of 271.40° True (T) (Fig. 23), consistent with a directed migration in rough parallel to Alaska's Beaufort Sea coastline. One hundred seventy-five (50%) whales were judged to be swimming at medium speed, with 74 (21%) swimming slowly, 23 (6%) swimming fast, and 19 (5%) still (Table 10). Of other behaviors first noted for bowhead whales, 70 (19%) were milling, 22 (6%) were diving, 8 (2%) were in cow-calf association, 6 (2%) were tail slapping, 4 (1%) were resting, 2 (1%) were breaching, and 1 was underwater blowing (Table 9). All behaviors noted are defined in Table 2.

During the first half of September, 50 of 86 (58%) bowheads were initially observed swimming (Table 9). Whales were generally moving in westerly directions, with a significant ($p < 0.001$) mean heading of 260.35°T (Fig. 23). Thirty-four (40%) whales were judged to be swimming at medium speed, with 27 (31%) swimming slowly, 18 (21%) still, and 3 (3%) swimming fast (Table 10). Of other behaviors first noted for bowhead whales, 15 (18%) were milling, 10 (12%) were diving, 5 (6%) were tail slapping, 3 (3%) were resting, 2 (2%) were in cow-calf association, and 1 (1%) was breaching (Table 9).

During the second half of September, 85 of 131 (64%) bowheads were initially observed swimming (Table 9). The greatest proportion (0.42) of directional movement was between west and northwest, with a significant ($p < 0.001$) mean heading of 277.41°T (Fig. 23). Sixty-five (49%) whales were judged to be swimming at medium speed, with 31 (24%) swimming slowly, and 13 (10%) swimming fast (Table 10). Of other behaviors first noted for bowhead whales, 37 (28%) were milling, 6 (5%) were diving, 2 (2%) were in cow-calf association, and 1 was underwater blowing (Table 9).

On 20 September, a close aggregation of 10 bowhead whale pods (22 animals) was observed milling near the east side of Harrison Bay, just north of Oliktok Point (Appendix B: Flight 15). Some pods appeared to be following others in wide arcs, at one point linking up to form a circle of whales approximately 100 m in diameter. Some whales appeared to be deliberately moving into this area, temporarily joining the central aggregation, then continuing past. Many whales in the aggregation were regularly producing highly visible underwater blows over the period of 24 minutes during which they were observed and videotaped. The activity occurred in relatively shallow water (15 m) and was associated with a faint brownish discoloration in the water that may have been mud stirred up from the bottom or may have represented a localized concentration of midwater copepods. Although some phalanx positioning was also observed, no overt echelon feeding, with mouths agape, was confirmed. On 29 September, another cluster of pods--including a very large pod of 23 whales--was briefly observed to be milling just east of this same location (Appendix B; Flight 20).

During the first half of October, 59 of 79 (75%) bowheads were initially observed swimming (Table 9). The greatest proportion (0.40) of directional movement was between west and northwest, with a significant ($p < 0.001$) mean heading of 263.37°T (Fig. 23). Fifty-one (65%) whales were judged to be swimming at medium speed, with 13 (16%) swimming slowly, and 1 (1%) swimming fast (Table 10). Of other behaviors first noted for bowhead whales, 7 (9%) were milling, 5 (6%) were diving, and 4 (5%) were in cow-calf association (Table 9).

From 16 through 28 October, 38 of 57 (66%) bowheads were initially observed swimming (Table 9). The greatest proportion (0.44) of directional movement was between west and northwest, with a significant ($p < 0.001$) mean heading of 289.08°T (Fig. 23). Twenty-five (44%) whales were judged to be swimming at medium speed, with 6 (11%) swimming fast, 3 (5%) swimming slowly, and 1 (2%) still (Table 10). Of other behaviors first noted for bowhead whales, 11 (19%) were milling, 1 (2%) was breaching, 1 (2%) was diving, 1 (2%) was resting, and 1 (2%) was tail slapping (Table 9).

Table 9
Semimonthly Summary of Bowhead Whales Observed, by Behavioral Category, Fall 1993

Behavior	1-15 Sep No. (%)	16-30 Sep No. (%)	1-15 Oct No. (%)	16-28 Oct No. (%)	Total No. (%)
Breaching	1 (1)	0	0	1 (2)	2 (1)
Cow-Calf	2 (2)	2 (2)	4 (5)	0	8 (2)
Diving	10 (12)	6 (5)	5 (6)	1 (2)	22 (6)
Milling	15 (18)	37 (28)	7 (9)	11 (19)	70 (19)
Resting	3 (3)	0	0	1 (2)	4 (1)
Swimming	50 (58)	85 (64)	59 (75)	38 (66)	232 (66)
Tail Slapping	5 (6)	0	0	1 (2)	6 (2)
Underwater Blow	0	1 (1)	0	0	1 (1)
(not noted)	0	0	4 (5)	4 (7)	8 (2)
TOTAL	86 (100)	131 (100)	79 (100)	57 (100)	353 (100)

Table 10
Semimonthly Summary of Bowhead Whales Observed, by Swimming Speed, Fall 1993

Swim Speed	1-15 Sep No. (%)	16-30 Sep No. (%)	1-15 Oct No. (%)	16-28 Oct No. (%)	Total No. (%)
Still (0 km/hr)	18 (21)	0	0	1 (2)	19 (5)
Slow (<2 km/hr)	27 (31)	31 (24)	13 (16)	3 (5)	74 (21)
Medium (2-4 km/hr)	34 (40)	65 (49)	51 (65)	25 (44)	175 (50)
Fast (>4 km/hr)	3 (3)	13 (10)	1 (1)	6 (11)	23 (6)
(not noted)	4 (5)	22 (17)	14 (18)	22 (38)	62 (18)
TOTAL	86 (100)	131 (100)	79 (100)	57 (100)	353 (100)

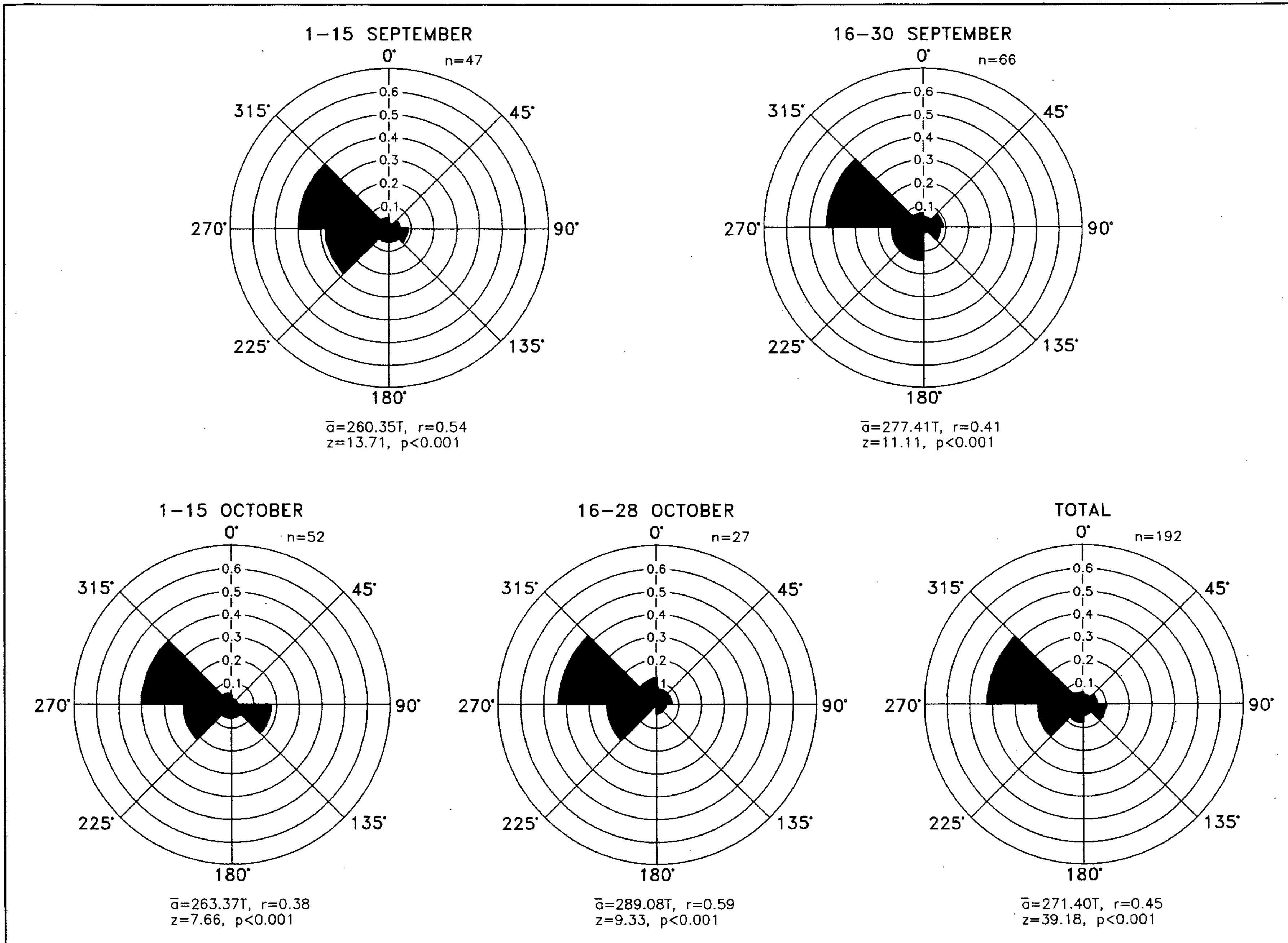

Figure 23. Semimonthly Summary of Swim Directions for Bowhead Whales, Fall 1993

D. Other Marine Mammal Observations

1. Gray Whale (*Eschrichtius robustus*): No gray whales were sighted during the study.

2. Belukha Whale (*Delphinapterus leucas*): Although the study area and survey altitude were designed to record the fall migration of bowhead whales, belukha whales, which undertake a somewhat parallel migration, were always counted and were considered suitable for selected analyses. Over the Fall 1993 field season, 37 sightings were made for a total of 149 belukha whales (Table 4) during 166.32 hr of survey effort (Table 3) for a seasonal relative abundance of 0.90 WPUE. Sightings of belukha whales were distributed between 143°W. and 154°W. longitudes; all but one of the whales were sighted south of 72°N. latitude (Fig. 24). The positions of most belukha sightings were between the 40 m- and 3,000-m isobaths (Figs. 2 and 24). Sizes of pods (or close aggregations of pods) ranged from 1 to 50 whales, with a mean of 4.03 (SD = 9.15, n = 37). Four belukha calves were noted. Belukha whales were observed in association with 0- to 50-percent sea ice, with a mean of 3.56-percent ice (SD = 11.58, n = 37).

During the first half of September, 7 sightings were made for a total of 8 belukha whales (Table 4) during 51.20 hr of survey effort (Table 3) and a relative abundance of 0.16 WPUE. The first belukha in the Alaskan Beaufort was sighted at 70°38.8'N. latitude, 144°55.1'W. longitude on 4 September. Sizes of pods (or close aggregations of pods) ranged from 1 to 2 whales, with a mean of 1.14 (SD = 0.38, n = 7). No belukha calves were noted during this period. Belukha whales were observed in association with 0- to 10-percent sea ice, with a mean of 4.43 percent ice (SD = 5.22, n = 7).

During the second half of September, 17 sightings were made for a total of 70 belukha whales (Table 4) during 36.73 hr of survey effort (Table 3) and a relative abundance of 1.91 WPUE. Sizes of pods (or close aggregations of pods) ranged from 1 to 30 whales, with a mean of 4.12 (SD = 6.88, n = 17). Three belukha calves were noted during this period. Belukha whales were observed in association with 0- to 50-percent sea ice, with a mean of 5.88-percent ice (SD = 16.61, n = 17).

During the first half of October, 8 sightings were made for a total of 66 belukha whales (Table 4) during 44.60 hr of survey effort and a relative abundance of 1.48 WPUE. Sizes of pods (or close aggregations of pods) ranged from 1 to 50 whales, with a mean of 8.25 (SD = 16.94, n = 8). One belukha calf was noted during this period. All belukha whales were observed in association with 0-percent sea ice.

From 16 through 28 October, 5 sightings were made for a total of 5 belukha whales (Table 4) during 33.78 hr of survey effort and a relative abundance of 0.15 WPUE. The last belukha sighted in the Alaskan Beaufort was at 71°56.3'N. latitude, 153°38.7'W. longitude on 20 October. Sizes of pods (or close aggregations of pods) were 1 whale each. No belukha calves were noted during this period. Belukha whales were observed in association with 0- to 1-percent sea ice, with a mean of 0.20 percent (SD = 0.45, n = 5).

3. Bearded Seal (*Erignathus barbatus*): Over the field season, 10 incidental sightings were made for a total of 13 bearded seals (Table 4). Eight of these sightings were distributed between 140°W. and 148°W. longitudes, south of the 100-m isobath (Figs. 2 and 25). Bearded seals were sighted on most of the flights from 1 September through 10 October (Table 4). All of the bearded seals were in the water when first sighted.

4. Ringed Seal (*Phoca hispida*): Over the field season, 87 incidental sightings were made for a total of 410 ringed seals (Table 4). Sightings were distributed between 140°W. and 156°W. longitudes, mostly south of the 2,000-m isobath (Figs. 2 and 26). Ringed seals were sighted from 1 September through 27 October, with over 97 percent of these seals observed from 1 through 20 September (Table 4). All of the ringed seals were in the water when first sighted.

5. Polar Bear (*Ursus maritimus*): Over the field season, 3 incidental sightings were made for a total of 5 polar bears (Table 4). Sightings were distributed between 146°W. and 157°W. longitudes, south of the

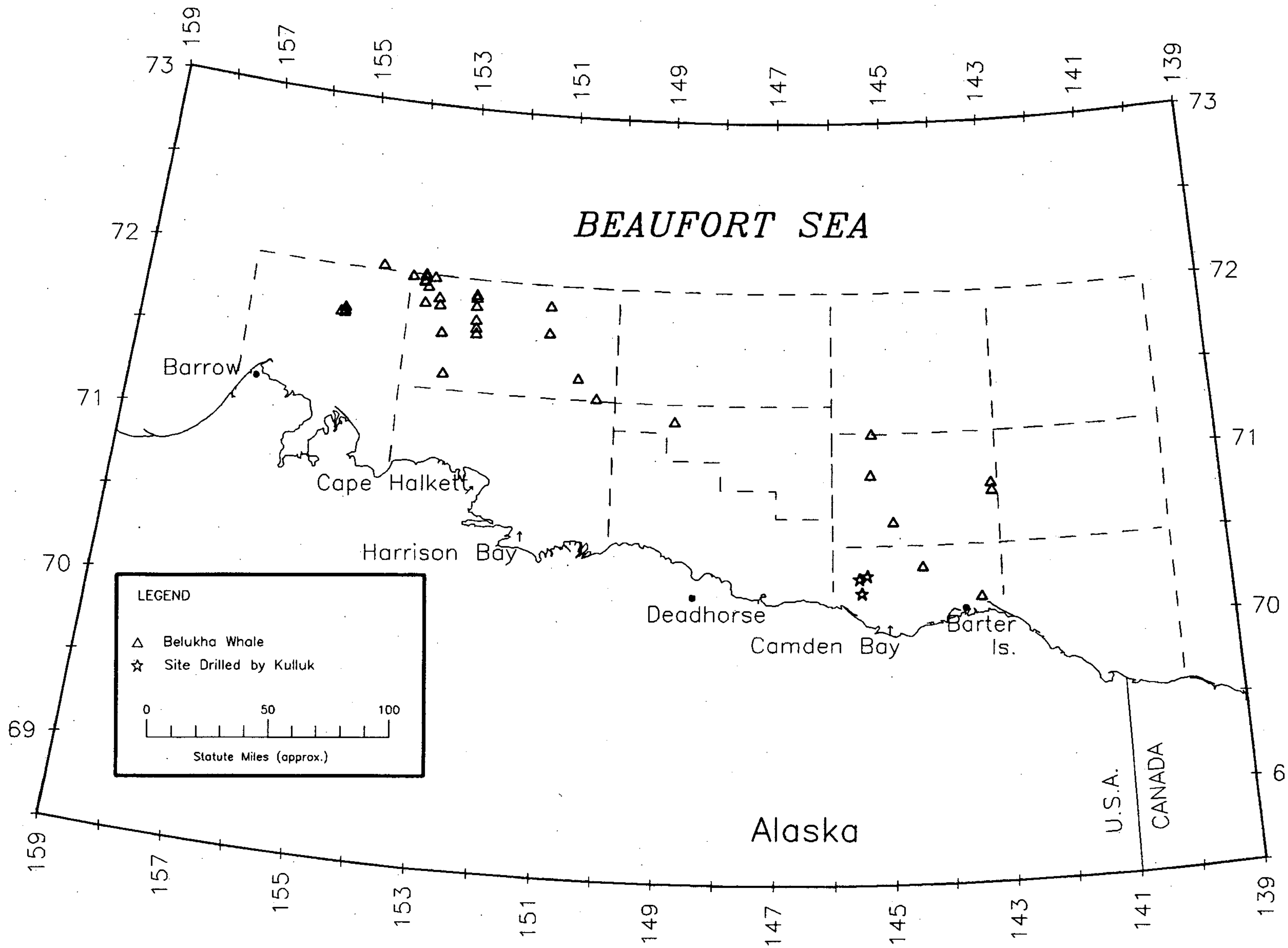

Figure 24. Map of Belukha Whale Sightings, Fall 1993

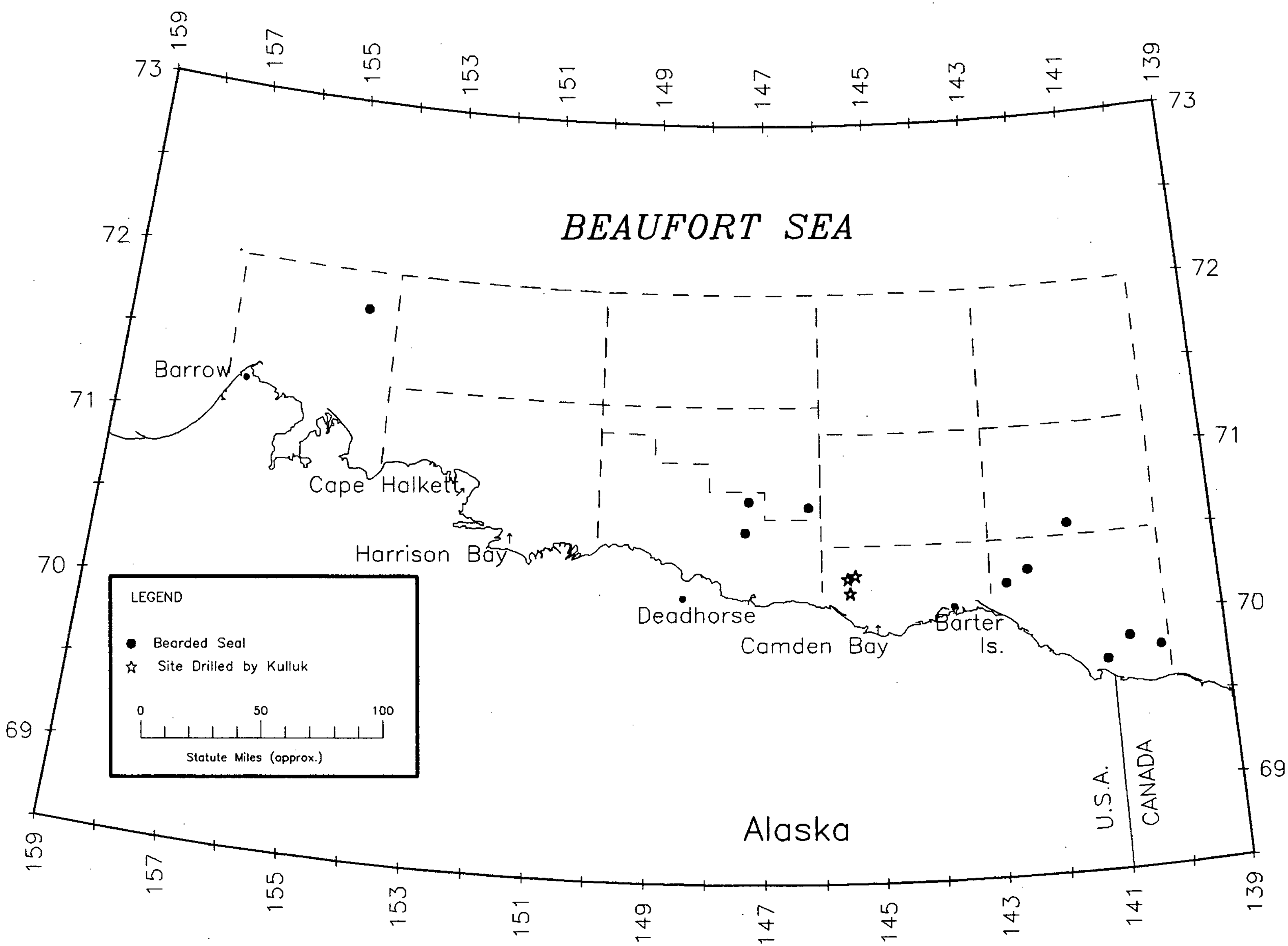

Figure 25. Map of Bearded Seal Sightings, Fall 1993

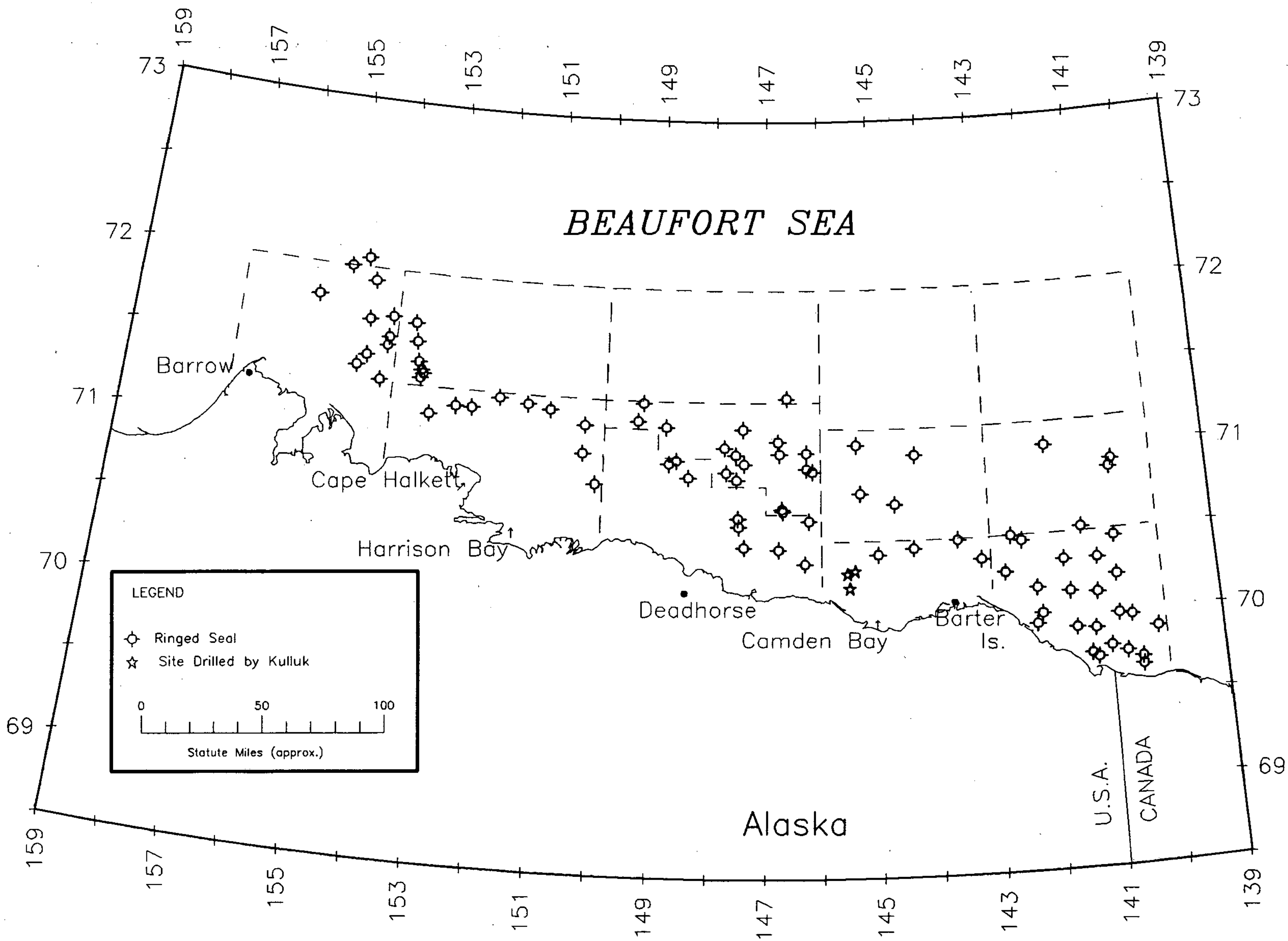

Figure 26. Map of Ringed Seal Sightings, Fall 1993

100-m isobath (Figs. 2 and 27). Polar bears were sighted from 1-12 September (Table 4). Four of the polar bears were in open water when first sighted and 1 was on ice. No polar bear kill sites and 4 sets of polar bear tracks on ice were recorded.

6. Pacific Walrus (*Odobenus rosmarus*): Over the field season, 2 incidental sightings were made for a total of 3 Pacific walruses (Table 4). Sightings were distributed between 154°W. and 155°W. longitudes, south of the 100-m isobath (Figs. 2 and 28). The walruses were sighted in open water on 11 September (Appendix B: Flight 9).

7. Unidentified Cetaceans: Over the field season, 2 incidental sightings were made for a total of 2 unidentified cetaceans (Table 4). Sightings were distributed between 144°W. and 156°W. longitudes, south of the 40-m isobath (Figs. 2 and 29).

8. Unidentified Pinnipeds: Over the field season, 12 incidental sightings were made for a total of 26 unidentified pinnipeds (Table 4). Sightings were distributed between 141°W. and 155°W. longitudes, south of the 400-m isobath (Figs. 2 and 30). These sightings were made from 1 September through 10 October (Table 4).

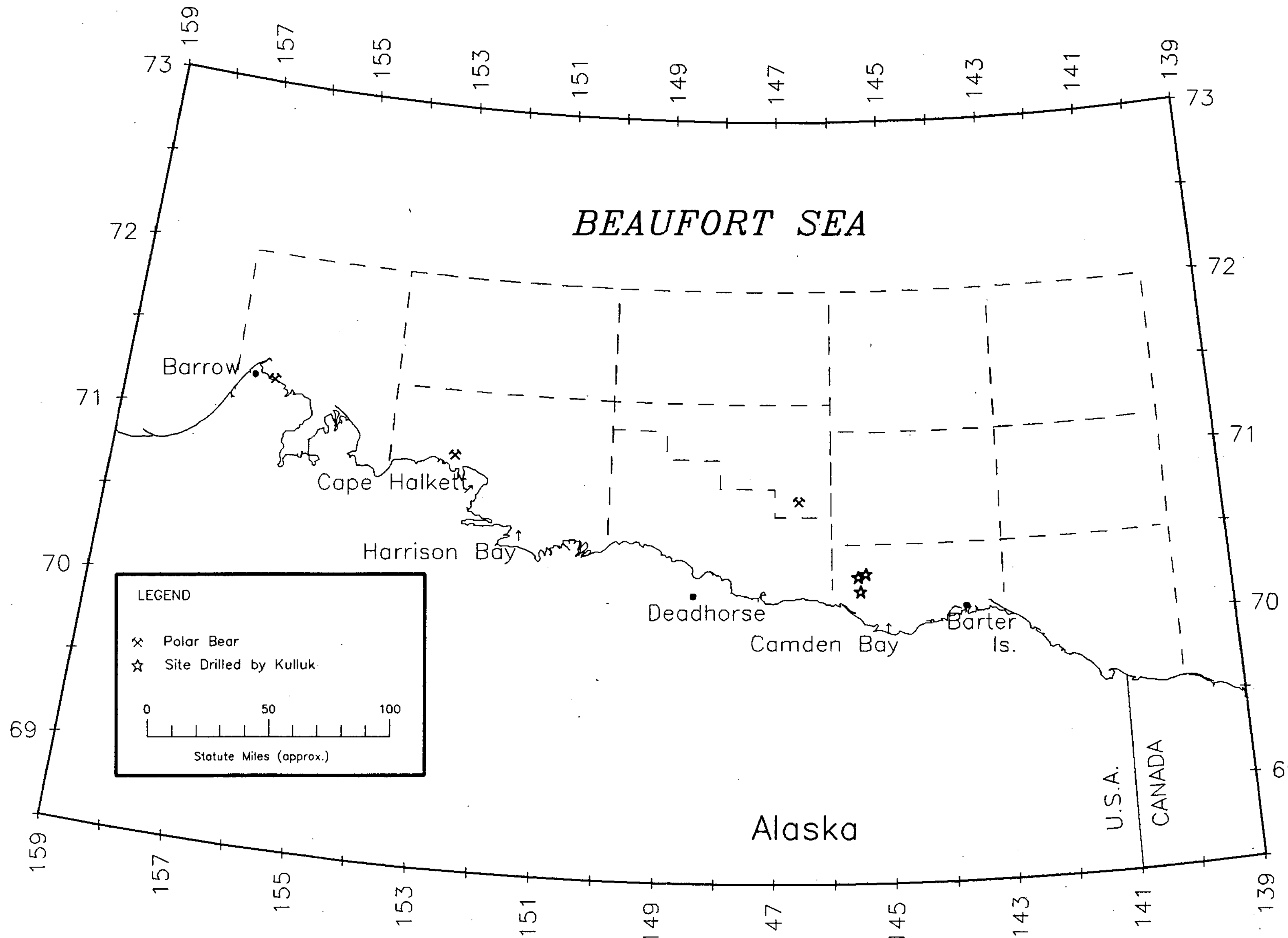

Figure 27. Map of Polar Bear Sightings, Fall 1993

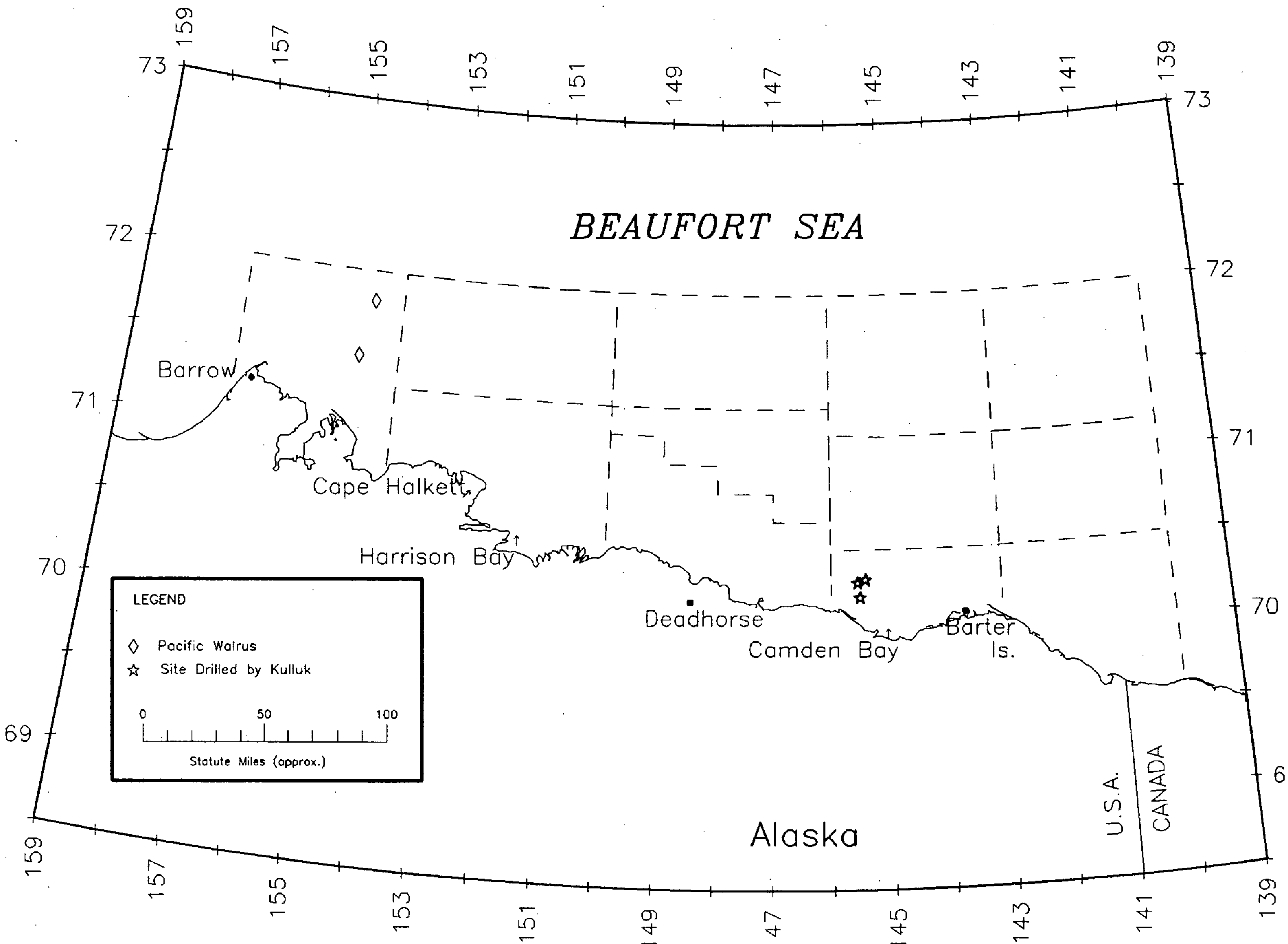

Figure 28. Map of Pacific Walrus Sightings, Fall 1993

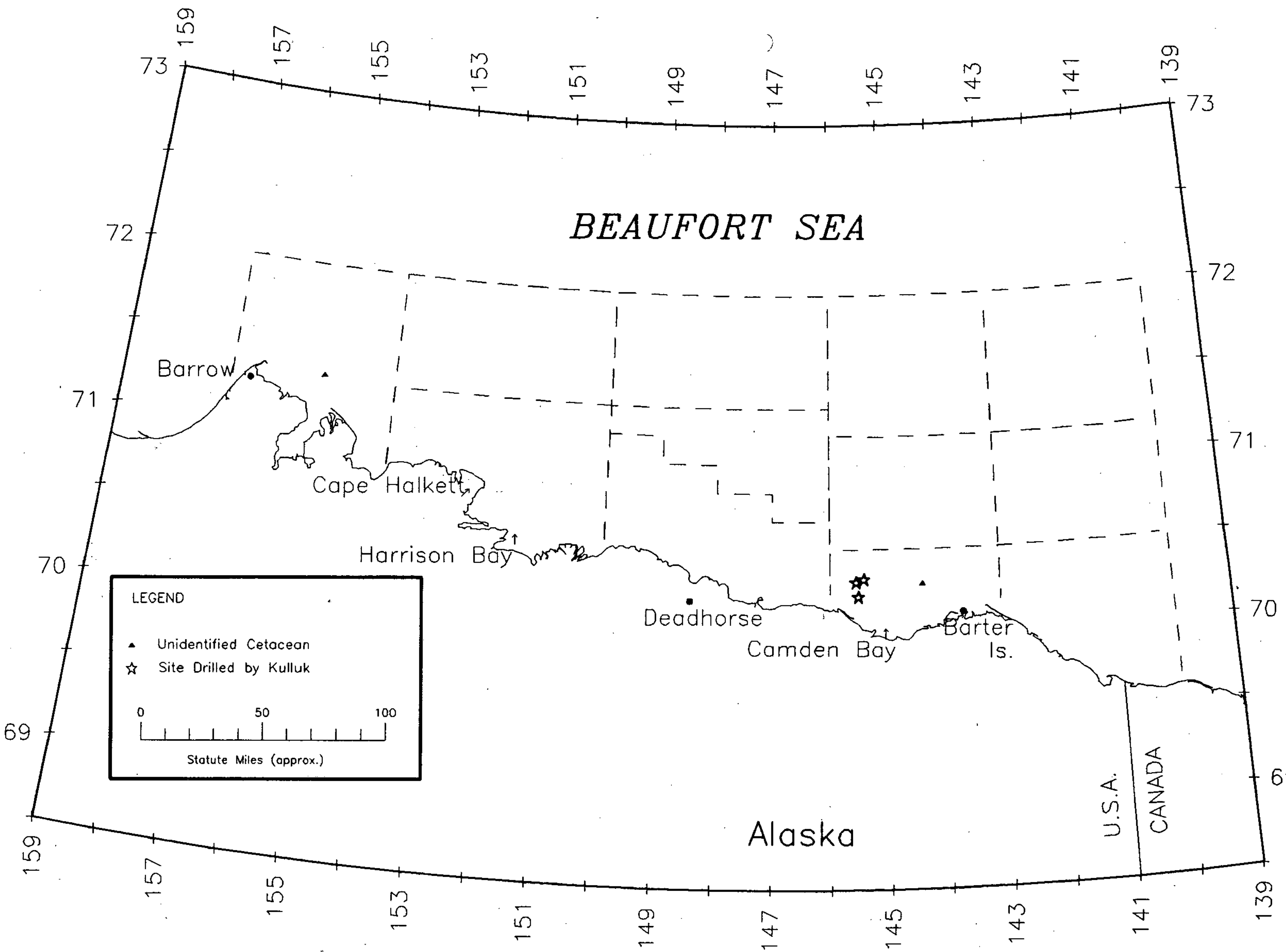

Figure 29. Map of Unidentified Cetacean Sightings, Fall 1993

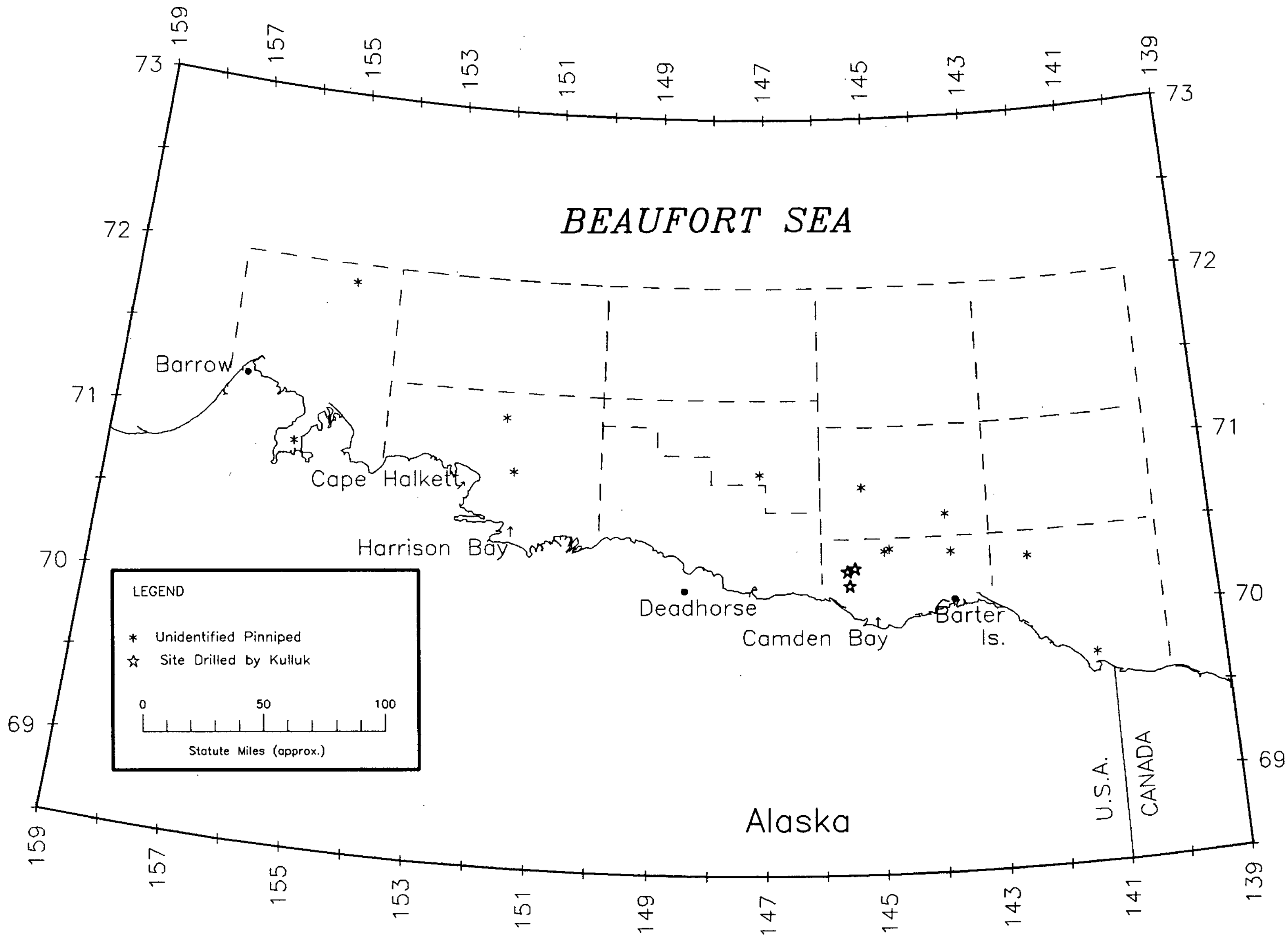

Figure 30. Map of Unidentified Pinniped Sightings, Fall 1993

IV. DISCUSSION

A. General Comparisons with Previous Surveys (1979-1992)

Most results of the present study are generally within the range of result values from previous MMS-funded endangered whale monitoring conducted during September and October (1979-1992) in the Beaufort Sea using similar survey methods (Ljungblad et al., 1987; Moore and Clarke, 1992; Treacy, 1988, 1989, 1990, 1991, 1992, 1993). Prior to Fall 1992, surveys in Block 12 were largely conducted from a modified Grumman Goose rather than a Twin Otter aircraft. Results for 1993 that varied greatly from previous values are described below.

The general ice coverage along the northern coast of Alaska during the 1993 navigation season was the third mildest in the Arctic Ocean for the years 1953 through 1993 and the mildest since MMS began bowhead whale monitoring in 1979 (USDOD, Navy, Naval Polar Oceanography Center, 1994).

Cloud cover over most of the study area was considered favorable for surveying in 1993, without recurrent periods of "down-to-the-deck" fog as in many previous field seasons.

The 36,809 km surveyed over the Alaskan Beaufort Sea in 1993 was the second highest total since in-house monitoring began in 1987. The average survey flight was 897.8 km, with some flights over 7 hours in duration. The 1993 total of 166.32 survey hours was higher than the mean of 123.71 survey hours (SD = 47.51, n = 6) for the years 1987 through 1992.

The number of sightings of bowhead whales (n = 235) and the number of bowhead whales counted (n = 353) during Fall 1993 were the second highest totals for all project surveys (1987-1993).

For September 1993, the relative abundance of bowhead whales in Block 3 of 3.03 WPUE (Table 11) was much higher than the mean September value in Block 3 (1979-1992) of 0.19 WPUE (SD = 0.31, n = 13). Values for relative abundance in all other survey blocks during September or October 1993 were within the range of values shown for the years 1979 through 1992 (Table 11).

The underwater blows exhibited by a close aggregation of 10 bowhead whale pods (22 whales) on 20 September 1993 just north of the east edge of Harrison Bay (Appendix B: Flight 15) was by far the most dramatic display of this type of behavior that we have observed since the study began in 1987. While feeding behavior was not confirmed for this 1993 aggregation, a large aggregation of 3 bowhead whale pods (19 whales) was observed to be feeding very near the same location on 7 October 1987 (Treacy, 1988).

Total numbers of belukha whales and other marine mammals sighted incidentally during Fall 1993 were within ranges established during previous project surveys in the Beaufort Sea (1987-1992).

B. Median and Mean Water Depth at Bowhead Sightings (1982-1993)

The median water depth at 75 sightings of bowhead whales made on randomized line transects in Regions I, II, and III (combined) (Fig. 2) during September and October 1993 was 29 m. This areawide median depth was less than the cumulative median depth of 37 m for the years 1982 through 1993 (n = 416). It was within the range of median areawide depths for previous years (range = 18 to 347 m), with only 1986 and 1989 in shallower water. Median water depths of 15 m for Region I and 29 m for Region II during 1993 were less than the cumulative median depths of 22 m and 37 m for these respective regions, whereas the 1993 value for Region III (44 m) was identical to the cumulative value. Bowhead whales were observed in shallower water in Region I for 1993 (15 m) than for any of the previous years (Table 12).

To determine whether any of the differences between the median water depth for 1993 and previous years (Table 12) were statistically significant, these values were tested using the Mann Whitney U test (Zar, 1984). The median water depth (all 3 regions combined) for the year 1993 showed a highly significant difference

IV

Table 11
Bowhead Whale Relative Abundance (WPUE) by Beaufort Sea Survey Block
during September and October, 1979-1993
(after Ljungblad et al. [1987], Moore and Clarke [1992],
and Treacy [1988, 1989, 1990, 1991, 1992, 1993])

	Survey Block												Other	Other
Year	1	2	3	4	5	6	7	8	9	10	11	12	Canadian Areas[2]	Alaskan Areas[3]
SEPTEMBER														
1979	0.08	0.00	0.00	0.09	10.08	0.73	0.00	[1]	[1]	[1]	[1]	0.00	[1]	[1]
1980	0.38	0.00	0.00	0.47	0.99	0.00	0.00	0.00	0.00	0.00	0.00	[1]	0.47	[1]
1981	0.22	0.00	0.00	6.13	6.20	0.00	0.00	0.00	0.00	[1]	0.00	[1]	0.32	0.00
1982	6.83	1.35	0.80	0.93	11.30	0.00	0.00	0.00	1.28	[1]	0.00	0.44	48.65	0.00
1983	0.11	0.87	0.61	0.00	0.00	1.51	1.90	0.00	0.36	0.21	0.53	2.28	[1]	0.00
1984	0.59	1.05	0.18	2.69	3.19	1.94	0.00	0.00	0.00	0.00	0.00	26.24	17.00	0.00
1985	0.54	0.00	0.00	2.21	1.74	0.39	0.00	0.00	0.00	0.00	0.00	0.00	6.52	0.00
1986	0.10	0.00	0.00	0.94	2.36	0.29	0.10	0.00	0.00	0.00	0.45	0.00	7.98	0.00
1987	0.74	0.00	0.00	1.32	0.72	0.31	0.00	[1]	0.00	[1]	0.00	0.26	0.66	0.33
1988	0.14	0.00	[1]	0.35	0.48	0.45	0.00	0.00	[1]	[1]	[1]	[1]	0.00	[1]
1989	2.37	0.33	0.00	6.23	0.71	0.33	1.52	[1]	0.00	0.00	[1]	0.73	[1]	0.00
1990	5.54	0.00	0.72	7.61	18.51	3.35	1.72	[1]	0.00	0.00	0.00	[1]	63.64	0.00
1991	0.00	0.00	0.00	0.30	0.20	1.88	0.00	0.00	0.00	0.00	0.00	0.00	20.50	0.00
1992	0.45	0.20	0.12	0.73	0.91	1.75	2.48	0.00	0.00	0.00	0.13	[1]	[1]	0.00
1993	4.39	0.00	3.03	4.07	2.11	0.00	0.00	0.00	0.00	0.00	0.00	1.93	[1]	0.00
OCTOBER														
1979	1.58	0.00	3.67	2.35	[1]	0.00	[1]	[1]	[1]	[1]	0.00	0.70	[1]	0.00
1980	0.10	1.18	0.35	0.29	0.00	0.00	[1]	[1]	[1]	0.00	0.00	0.00	0.00	0.00
1981	0.89	0.00	0.52	4.22	0.00	0.00	0.00	[1]	[1]	[1]	0.00	0.00	[1]	[1]
1982	0.19	0.00	2.48	0.00	0.70	0.00	[1]	0.00	0.00	0.00	0.19	1.87	0.46	0.00
1983	0.00	0.00	0.49	0.00	0.00	0.27	2.17	[1]	[1]	0.00	0.00	0.75	[1]	0.00
1984	0.29	0.26	1.24	0.00	1.37	0.00	[1]	[1]	[1]	0.00	3.05	2.37	3.70	0.00
1985	2.26	0.00	0.40	0.00	0.00	0.00	0.00	0.00	[1]	0.00	9.00	0.53	0.00	0.00
1986	1.00	0.38	0.47	0.71	[1]	0.00	[1]	[1]	0.00	0.00	0.00	0.91	[1]	0.00
1987	0.19	0.00	2.94	0.62	0.32	0.00	0.00	0.00	0.00	0.00	0.00	1.71	0.00	0.00
1988	0.18	0.26	1.12	0.12	0.14	0.00	0.00	[1]	0.00	[1]	0.19	1.01	0.00	0.00
1989	1.32	0.00	5.58	0.00	0.00	0.00	0.00	[1]	[1]	0.00	0.00	12.98	[1]	0.00
1990	3.00	0.00	2.14	2.17	[1]	2.86	[1]	[1]	[1]	0.00	0.97	0.74	[1]	0.00
1991	0.07	2.23	0.27	1.48	4.36	0.00	1.39	0.00	0.00	0.00	0.00	1.04	0.49	0.55
1992	0.00	0.68	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	16.35	[1]	0.00
1993	0.88	0.00	1.78	2.32	2.19	1.24	0.00	0.00	0.00	0.00	0.00	4.40	0.00	0.00

[1] No survey effort.
[2] Between 140°W. and 141°W. longitudes north of 72°N. latitude or east of 140°W. longitude.
[3] Between 141°W. and 157°W. longitudes north of 72°N. latitude.

Table 12
Central-Tendency Statistics for Water Depth (in meters) at Random Sightings of Bowhead Whales (September-October), by Year and Region, 1982-1993

Year	Region	SI[1]	Median	CI[2]	Mean	SD[3]	Range
1982	I	8	17	11-457	113.4	176.23	11-457
	II	30	27	22-38	30.6	9.03	16-51
	III	5	40	[4]	43.4	11.24	29-59
	All 3	43	29	22-38	47.5	79.22	11-457
1983	I	9	69	22-2,323	393.7	740.61	22-2,323
	II	5	1,289	[4]	945.0	858.85	53-2,021
	III	9	797	49-1,902	969.7	740.24	49-1,902
	All 3	23	347	49-1,737	738.9	782.96	22-2,323
1984	I	15	42	27-69	53.3	41.43	18-177
	II	9	38	22-82	43.7	18.73	22-82
	III	14	48	22-274	90.4	130.05	18-485
	All 3	38	43	27-59	64.7	84.09	18-485
1985	I	3	183	[4]	219.3	221.74	18-457
	II	9	31	20-38	30.4	5.00	20-38
	III	1	[4]	[4]	[4]	[4]	64[5]
	All 3	13	31	20-183	76.6	122.13	18-457
1986	I	4	18	[4]	51.0	69.37	13-155
	II	12	17	9-40	60.8	144.79	7-519
	III	22	34	22-48	34.0	13.91	11-57
	All 3	38	26	18-44	44.3	82.99	7-519
1987	I	4	20	[4]	19.2	4.86	13-24
	II	9	27	15-38	27.3	7.60	15-38
	III	20	41	29-55	49.8	41.38	18-219
	All 3	33	37	24-44	40.0	34.54	13-219
1988	I	4	36	[4]	40.5	15.11	29-62
	II	4	44	[4]	44.8	13.60	29-62
	III	5	46	[4]	90.4	116.40	24-298
	All 3	13	42	29-62	61.0	72.17	24-298
1989	I	15	18	9-20	16.0	4.58	9-24
	II	1	[4]	[4]	[4]	[4]	44[5]
	III	3	49	[4]	49.3	9.50	40-59
	All 3	19	18	13-40	22.7	14.39	9-59
1990	I	3	31	[4]	29.3	13.58	15-42
	II	17	37	29-38	33.6	7.05	15-38
	III	68	40	37-48	40.5	10.49	16-60
	All 3	88	38	37-38	38.8	10.43	15-60

Table 12
Central-Tendency Statistics for Water Depth (in meters) at Random Sightings of Bowhead Whales (September-October), by Year and Region, 1982-1993
(Continued)

Year	Region	SI[1]	Median	CI[2]	Mean	SD[3]	Range
1991	I	0	[4]	[4]	[4]	[4]	[4]
	II	7	66	[4]	126.7	100.04	27-274
	III	6	118	[4]	132.2	92.05	48-232
	All 3	13	66	48-238	129.2	92.42	27-274
1992	I	8	40	13-329	70.3	105.24	13-329
	II	3	46	[4]	119.0	126.44	46-265
	III	8	55	44-57	52.9	4.29	44-57
	All 3	19	46	37-55	70.6	81.37	13-329
1993	I	12	15	13-18	16.1	2.23	13-20
	II	24	29	22-38	30.0	9.58	15-53
	III	39	44	27-48	44.3	34.24	9-229
	All 3	75	29	24-38	35.2	27.25	9-229
Cumulative (1982-1993)	I	85	22	18-31	87.5	265.55	9-2,323
	II	130	37	29-37	77.3	237.59	7-2,021
	III	201	44	40-48	91.3	246.45	9-1,902
	All 3	416	37	37-38	86.1	247.24	7-2,323

1 SI = random sightings.
2 CI ≥ 99-percent confidence interval.
3 SD = standard deviation.
4 Insufficient sample size.
5 One datum.

(p <0.005) when compared to medians for the years 1983, 1984, 1990, 1991, and 1992. Analysis by region showed a similarity between 1993 and 1989 in Region I (between 150°W. and 153°30'W. longitudes), in that each of these two years showed a high degree of statistical significance (p <0.005) between their median depth and that for the years 1983, 1984, 1988, and 1992. There was also a high degree of statistical significance between 1993 and the median depths for 1983, 1991, and 1992 in Region II (between 146°W. and 150°W. longitudes) and between 1993 and the median depths for 1983, 1991, and 1992 in Region III (between 141°W. and 146°W. longitudes) (Table 13).

The median water depth for the year 1987 (37 m) was considered typical, in that it was identical to the cumulative median for the years 1982 through 1993 (Table 12). Of the years when bowheads tended to migrate in water that was deeper than in 1987, the years 1983, 1991, and 1992 showed highly significant (p <0.005) differences from the 37-m median value. Likewise, of the years when whales tended to migrate in water that was shallower than in 1987, the year 1989 showed a difference that was considered highly significant (Table 13).

A high level of significance (p <0.005) was noted between the 1983 median value (all 3 regions combined) and the median values for other years except 1991 (Table 13), due to the fact that the 1983 median water depth of 347 m was greater by far than the median for other years (Table 12). A high degree of significance (p <0.005) between 1983 and other years was shown, to a lesser extent, in bathymetric Regions II and III (Table 13).

A high level of significance (p <0.005) was noted between the 1989 median value (all 3 regions combined) and the median values for other years, except 1986 and 1993 (Table 13), because the 1989 median water depth of 18 m was clearly shallower than the median depth for other years (Table 12). Such attained levels (p <0.005) between 1989 and other years were shown, to a lesser extent, in Region I (Table 13).

Mean water depths were also calculated for Regions I, II, and III. Mean values, although less descriptive of the apparent "axis" of the migration, were considered more robust for demonstrating significant differences between years.

The mean water depth at 75 sightings of bowhead whales made on randomized line transects in Regions I, II, and III (combined) during September and October 1993 was 35.2 m (Table 12). The areawide mean depth for 1993 (35.2 m) was within the range of areawide mean depths for the years 1982 through 1992 (previous values ranged from 22.7 to 738.9 m) and was less than for other single years, except for 1989 (22.7 m). This areawide mean depth was also less than the cumulative mean depth of 86.1 m for the years 1982 through 1993 (n = 416). Mean water depths of 16.1 m for Region I, 30.0 m for Region II, and 44.3 m for Region III during 1993 were less than the cumulative mean depths of 87.5 m, 77.3 m, and 91.3 m, respectively, for these regions. The mean depth of 16.1 m in Region I for 1993 was less than for previous years, except for a 16.0-m median depth in Region I for 1989. The mean depth of 30.0 m in Region II for 1993 was less than for previous years, except for a 27.3 median depth in Region II for 1987 (Table 12).

Comparison of the means using ANOVA and the Tukey test (Zar, 1984) showed that 1983 was unique among other years in the spatial distribution of the fall bowhead migration. Differences between the mean for 1983 and all other years (including 1993) were considered very highly significant (p <0.001) in all three regions combined and in Regions II and III, thus mirroring differences noted between the 1983 median and the medians for other years. Differences in mean water depths between all other years, including 1993, were not considered statistically significant (Table 14).

The reasons for the offshore (deep-water) migratory route of 1983 and the comparatively shallower route followed in other years may be attributable to general ice cover (see Sec. IV.D). Differences in human activity levels, oceanographic conditions, and the possible indirect effect of heavy ice cover on prey availability are additional potential factors. Ice cover probably has the greatest potential for interacting with environmental conditions that, in turn, may have biological significance to migrating bowhead whales (e.g., net primary production, availability of leads, water temperature). During 1983, the most severe ice year since

Table 13
Interyear Correlation (nonparametric) of the Median Water Depths at Random Bowhead Whale Sightings (September-October) Using the Mann-Whitney U Test, 1982-1993
(Page 1 of 4)

REGION I	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1983	U′ = 54.0 p ≤ 0.10										
1984	U′ = 81.5 p < 0.20	U = 92.5 p < 0.20									
1985	U′ = 18.0 p > 0.20	U = 14.5 p > 0.20	U′ = 30.5 p > 0.20								
1986	U = 16.0 p > 0.20	U = 31.0 p < 0.10	U = 45.0 p < 0.20	U = 10.0 p > 0.20							
1987	U = 16.5 p > 0.20	U = 34.5 p < 0.02	U = 55.5 p < 0.01	U = 9.5 p > 0.20	U′ = 8.5 p > 0.20						
1988	U′ = 21.0 p > 0.20	U = 23.0 p > 0.20	U′ = 30.5 p > 0.20	U = 8.0 p > 0.20	U′ = 12.0 p > 0.20	U′ = 16.0 p < 0.05					
1989	U = 76.5 p > 0.20	U = 134.0 p < 0.001	U = 216.5 p < 0.001	U = 39.0 p < 0.10	U = 37.0 p > 0.20	U = 41.5 p > 0.20	U = 60.0 p ≤ 0.001				
1990	U = 13.0 p > 0.20	U = 20.0 p > 0.20	U = 31.5 p > 0.20	U = 7.0 p > 0.20	U′ = 7.0 p > 0.20	U′ = 9.0 p > 0.20	U = 7.5 p > 0.20	U′ = 35.5 p < 0.20			
1991	1	1	1	1	1	1	1	1	1		
1992	U′ = 39.5 p > 0.20	U = 48.5 p > 0.20	U = 68.0 p > 0.20	U = 16.0 p > 0.20	U′ = 22.5 p > 0.20	U′ = 26.5 p < 0.20	U = 16.5 p > 0.20	U′ = 106.5 p < 0.002	U′ = 15.5 p > 0.20	1	
1993	U = 66.0 p ≤ 0.20	U = 108.0 p < 0.001	U = 176.5 p < 0.001	U = 33.0 p < 0.05	U = 31.0 p > 0.20	U = 34.0 p > 0.20	U = 48.0 p ≤ 0.002	U = 96.0 p > 0.20	U = 28.5 p < 0.20	1	U = 84.5 p < 0.005

Table 13
Interyear Correlation (nonparametric) of the Median Water Depths at Random Bowhead Whale Sightings (September-October) Using the Mann-Whitney U Test, 1982-1993
(Page 2 of 4)

REGION II

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1983	U′ = 150.0 p < 0.001										
1984	U′ = 193.0 p < 0.10	U = 42.0 p ≤ 0.01									
1985	U = 136.0 p > 0.20	U = 45.0 p ≤ 0.001	U = 62.0 p < 0.10								
1986	U = 254.0 p < 0.05	U = 58.0 p ≤ 0.002	U = 86.5 p < 0.05	U = 76.5 p < 0.20							
1987	U = 155.0 p > 0.20	U = 45.0 p ≤ 0.001	U = 63.5 p < 0.10	U = 53.0 p > 0.20	U′ = 70.5 p > 0.20						
1988	U′ = 103.0 p ≤ 0.02	U = 19.0 p ≤ 0.05	U′ = 20.5 p > 0.20	U′ = 29.0 p < 0.20	U′ = 41.0 p ≤ 0.05	U′ = 33.0 p ≤ 0.02					
1989	U′ = 29.0 p < 0.20	U = 5.0 [1]	U′ = 5.5 p > 0.20	U′ = 9.0 p ≤ 0.20	U′ = 11.0 p > 0.20	U′ = 9.0 p ≤ 0.20	U = 2.0 [1]				
1990	U′ = 280.5 p > 0.20	U = 85.0 p < 0.001	U = 101.5 p < 0.20	U′ = 108.5 p < 0.10	U′ = 146.0 p < 0.10	U′ = 114.0 p ≤ 0.05	U = 54.0 p < 0.10	U = 17.0 p ≤ 0.20			
1991	U′ = 195.0 p < 0.001	U = 26.00 p < 0.20	U′ = 51.0 p ≤ 0.05	U′ = 56.0 p ≤ 0.01	U′ = 74.0 p < 0.01	U′ = 58.5 p < 0.005	U′ = 22.0 p < 0.20	U′ = 6.0 [1]	U′ = 104.0 p < 0.005		
1992	U′ = 88.0 p ≤ 0.002	U = 13.0 p ≤ 0.20	U′ 21.0 p > 0.20	U′ = 27.0 p ≤ 0.01	U′ = 33.0 p < 0.05	U′ = 27.0 p ≤ 0.01	U′ = 9.0 p > 0.20	U′ = 3.0 [1]	U′ = 51.0 p ≤ 0.002	U = 13.0 p > 0.20	
1993	U = 380.5 Z = 0.35 p > 0.20	U = 119.5 p < 0.001	U = 158.5 p < 0.05	U = 115.0 p > 0.20	U′ = 196.5 p < 0.10	U′ = 124.0 p > 0.20	U = 81.5 p < 0.05	U = 23.0 p ≤ 0.20	U = 243.0 p > 0.20	U = 154.0 p < 0.001	U = 70.0 p < 0.005

Table 13
Interyear Correlation (nonparametric) of the Median Water Depths at Random Bowhead Whale Sightings (September-October) Using the Mann-Whitney U Test, 1982-1993
(Page 3 of 4)

REGION III	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1983	U′ = 43.5 p < 0.005										
1984	U′ = 36.5 p > 0.20	U = 117.0 p < 0.001									
1985	U′ = 5.0 [1]	U = 8.0 p > 0.20	U′ = 11.0 p > 0.20								
1986	U = 77.0 p ≤ 0.20	U = 195.5 p < 0.001	U = 216.0 p < 0.05	U = 22.0 p ≤ 0.10							
1987	U = 54.5 p > 0.20	U = 173.0 p < 0.001	U = 159.0 p > 0.20	U = 19.0 p ≤ 0.20	U′ = 284.0 p < 0.10						
1988	U = 13.0 p > 0.20	U = 43.0 p ≤ 0.005	U = 38.0 p > 0.20	U = 4.0 [1]	U′ = 70.5 p > 0.20	U′ = 56.0 p > 0.20					
1989	U′ = 10.0 p > 0.20	U = 25.5 p < 0.02	U′ = 24.5 p > 0.20	U = 3.0 [1]	U′ = 54.0 p ≤ 0.10	U′ = 41.5 p > 0.20	U′ = 10.0 p > 0.20				
1990	U = 200.5 Z = 0.66 p > 0.20	U = 596.5 Z = 4.60 p < 0.001	U = 572.5 Z = 1.18 p > 0.20	U = 68.0 Z = 1.68 p < 0.10	U′ = 946.0 Z = 1.86 p < 0.10	U = 732.0 Z = 0.51 p > 0.20	U = 189.0 Z = 0.40 p > 0.20	U = 154.0 Z = 1.47 p < 0.20			
1991	U′ = 25.0 p ≤ 0.10	U = 47.5 p < 0.02	U′ = 58.0 p > 0.20	U = 3.0 [1]	U′ 121.0 p ≤ 0.001	U′ = 100.0 p < 0.02	U′ = 24.0 p < 0.20	U′ = 13.0 p > 0.20	U′ = 354.0 Z = 2.96 p < 0.005		
1992	U′ = 31.0 p < 0.20	U = 74.5 p < 0.001	U′ = 74.0 p > 0.20	U = 9.0 [1]	U′ = 170.5 p < 0.001	U′ = 126.0 p ≤ 0.02	U′ = 31.0 p < 0.20	U′ = 14.5 p > 0.20	U′ = 477.5 Z = 3.47 p < 0.001	U = 34.5 p > 0.20	
1993	U = 114.5 p > 0.20	U = 341.5 p < 0.001	U = 338.5 p < 0.20	U = 37.0 p < 0.20	U′ = 520.0 Z = 1.36 p < 0.20	U = 425.5 Z = 0.56 p > 0.20	U = 104.0 p > 0.20	U = 84.5 p > 0.20	U = 1,384.0 Z = 0.37 p > 0.20	U = 201.5 p < 0.005	U = 271.5 p < 0.001

Table 13
Interyear Correlation (nonparametric) of the Median Water Depths at Random Bowhead Whale Sightings (September-October) Using the Mann-Whitney U Test, 1982-1993
(Page 4 of 4)

ALL THREE REGIONS (COMBINED)

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1983	U′ = 882.0 Z = 5.21 p < 0.001										
1984	U′ =1,138.5 Z = 3.04 p < 0.005	U = 717.5 Z = 4.17 p < 0.001									
1985	U′ = 316.5 Z = 0.71 p > 0.20	U = 249.5 p < 0.001	U = 297.5 p > 0.20								
1986	U = 898.0 Z = 0.76 p > 0.20	U = 786.0 Z = 5.19 p < 0.001	U = 1,043.0 Z = 3.33 p < 0.001	U = 314.0 p < 0.20							
1987	U′ = 798.5 Z = 0.93 p > 0.20	U = 666.5 Z = 4.77 p < 0.001	U = 809.5 Z = 2.10 p < 0.05	U = 223.0 p > 0.20	U′ = 760.5 Z = 1.53 p < 0.20						
1988	U′ = 414.0 Z = 2.60 p < 0.01	U = 245.5 p < 0.002	U′ = 248.0 p > 0.20	U′ = 104.5 p > 0.20	U′ = 356.5 p < 0.02	U′ = 291.0 p < 0.10					
1989	U = 598.0 Z = 2.89 p < 0.005	U = 417.5 p < 0.001	U = 617.0 p < 0.001	U = 198.5 p < 0.005	U = 457.0 p < 0.20	U = 480.5 p < 0.002	U = 214.0 p < 0.001				
1990	U′ =2,473.5 Z = 2.85 p < 0.005	U = 1,729.5 Z = 8.10 p < 0.001	U = 1,949.5 Z = 1.47 p < 0.20	U′ = 682.5 Z = 1.12 p > 0.20	U′ = 2,227.5 Z = 2.95 p < 0.005	U′ = 1,717.5 Z = 1.54 p < 0.20	U = 674.5 Z = 1.03 p > 0.20	U′ = 1,353.0 Z = 4.21 p < 0.001			
1991	U′ = 503.0 Z = 4.33 p < 0.001	U = 213.0 p < 0.05	U′ = 373.5 p < 0.01	U′ = 134.5 p < 0.02	U′ = 446.0 p < 0.001	U′ = 377.0 p < 0.001	U′ = 135.0 p ≤ 0.01	U′ = 236.0 p < 0.001	U′ = 999.0 Z = 4.33 p < 0.001		
1992	U′ = 663.0 Z = 3.88 p < 0.001	U = 368.5 p < 0.001	U′ = 410.0 p > 0.20	U′ = 170.5 p < 0.10	U′ = 578.0 p < 0.001	U′ = 470.5 p < 0.005	U′ = 150.5 p > 0.20	U′ = 325.5 p < 0.001	U′ = 1,185.5 Z = 2.85 p < 0.005	U = 193.5 p < 0.01	
1993	U′ =1,614.5 Z = 0.01 p > 0.20	U = 1,545.5 Z = 5.72 p < 0.001	U = 1,981.0 Z = 3.38 p < 0.001	U = 568.0 Z = 0.94 p > 0.20	U′ = 1,580.5 Z = 0.95 p > 0.20	U = 1,381.5 Z = 0.96 p > 0.20	U = 679.5 Z = 2.25 p < 0.05	U′ = 1,007.0 Z = 2.77 p < 0.01	U = 4,200.5 Z = 3.00 p < 0.005	U = 886.5 Z = 4.69 p < 0.001	U = 1,111.0 Z = 3.75 p < 0.001

[1] Insufficient sample size.

Table 14
Interyear Correlation (parametric) of the Mean Water Depths at Random Bowhead Whale Sightings (September-October) Using Analysis of Variants (ANOVA) and the Tukey Test, 1982-1993

REGION I[1]
ANOVA F = 1.691, $p < 0.20$

Tukey Test:

(1989)	(1993)	(1987)	(1990)	(1988)	(1986)	(1984)	(1992)	(1982)	(1985)	(1983)
16.0	16.0	19.3	29.3	40.5	51.3	53.4	70.3	113.4	219.3	393.7

REGION II
ANOVA F = 13.070, $p << 0.001$

Tukey Test:

(1987)	(1993)	(1985)	(1982)	(1990)	(1984)	(1989)	(1988)	(1986)	(1992)	(1991)	(1983)
27.3	30.0	30.4	30.6	33.6	43.7	44.0[2]	44.8	60.8	119.0	126.7	945.0

(1984) through (1983): ($p < 0.001$)

REGION III
ANOVA F = 26.382, $p << 0.001$

Tukey Test:

(1986)	(1990)	(1982)	(1993)	(1989)	(1987)	(1992)	(1985)	(1984)	(1988)	(1991)	(1983)
34.1	40.5	43.4	44.3	49.3	49.9	50.2	64.0[2]	90.4	90.4	132.2	969.8

(1987) through (1983): ($p < 0.001$)

ALL THREE REGIONS (COMBINED)
ANOVA F = 26.057, $p << 0.001$

Tukey Test:

(1989)	(1993)	(1990)	(1987)	(1986)	(1982)	(1988)	(1984)	(1992)	(1985)	(1991)	(1983)
22.7	35.2	38.8	40.0	44.3	47.5	61.0	64.7	68.6	76.6	129.2	739.0

(1982) through (1983): ($p << 0.001$)

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[1] No data for Region I during 1991.
[2] One datum.

1975 (USDOD, Navy, Naval Polar Oceanography Center, 1993), the bowhead migration was observed in water almost an order of magnitude deeper than for other years (Table 12).

During 1993, the mildest ice year since the beginning of the surveys in 1979 (USDOD, Navy, Naval Polar Oceanography Center, 1993), the bowhead migration was observed at a less-than-average areawide median and mean depth, which was reflected by a less-than-average median depth in Regions I and II and less-than-average mean depths in each of the three regions (Table 12).

In general, mean water depths at sightings of bowhead whales were skewed to the deeper (north) side of the migration axis (median), with cumulative mean values for each region (1982-1993) approximately twice as great (as deep) as the cumulative medians (Table 12). The reason for the differences between the median and mean values is unknown but may simply reflect the increasing gradient of the sea floor farther offshore.

C. Potential Responses of Bowheads to Survey Aircraft

During the 1993 field season, there were no sightings of bowhead whales for which definite responses to the survey aircraft were apparent. Although it was not possible to determine if any responses would have been a direct result of overflight by survey aircraft, sudden overt changes in whale behavior were sought. Such changes included an abrupt dive, course diversion, or cessation of behavior ongoing at first sighting.

D. Potential Effect of General Ice Cover on WPUE (1979-1993)

There were 353 bowhead whales observed during 165.22 hr for a relative abundance of 2.14 WPUE for the combined months of September and October 1993 in Survey Blocks 1 through 12. The relative abundance in the primary study area was 2.48 WPUE during September and 1.75 WPUE during October. The combined September and October relative abundance of 2.14 WPUE for 1993 was considered representative of the cumulative relative abundance (2.04 WPUE) found during light ice years (Table 15).

The years 1980, 1983, 1988, and 1991 were categorized as having "heavy" ice cover during the navigation season. These 4 years are ranked as having the severest seasonal ice for the years 1979 through 1993 and show distances between Point Barrow and the five-tenths ice concentration on 15 September ranging from 10 nm to 25 nm (USDOD, Navy, Naval Polar Oceanography Center, 1994).

The years 1984, 1985, and 1992, categorized as having "moderate" ice cover during the open-water season, are ranked next in seasonal ice severity for the years 1979 through 1993 and show distances between Point Barrow and the five-tenths ice concentration on 15 September ranging from 50 nm to 75 nm (USDOD, Navy, Naval Polar Oceanography Center, 1994).

The years 1979, 1981, 1982, 1986, 1987, 1989, 1990, and 1993, categorized as having "light" ice cover during the open-water season, are ranked as having the least severe seasonal ice for the years 1979 through 1993 and show distances between Point Barrow and the five-tenths ice concentration on 15 September ranging from 85 nm to 185 nm (USDOD, Navy, Naval Polar Oceanography Center, 1994).

Table 15 shows a low relative abundance of bowhead whales in the primary study area (Survey Blocks 1-12) during September and October (combined) for years of heavy ice cover (0.46 WPUE), a middle-range value for moderate ice years (1.55 WPUE), and a high value for light ice years (2.04 WPUE). A Kruskal-Wallis single factor analysis of variance by ranks (Zar, 1984) showed that ice-year categories were significantly related ($p < 0.05$) to annual relative abundance.

Although cumulative values for the three ice-year categories (Table 15) and the Kruskal-Wallis test suggest a relationship to annual relative abundance, it is clear that WPUE value is not totally dependent on general ice coverage. While the mean WPUE for heavy ice years ($\bar{x}$ = 0.46, SD = 0.15, n = 4) appears separable from other ice-year categories, the SD of the mean WPUE for light ice years ($\bar{x}$ = 2.24, SD = 1.37, n = 8)

Table 15
Relative Abundance (WPUE) of Bowhead Whales within the Primary Study Area (Survey Blocks 1-12) during September and October[1], by Year and General Ice Coverage, 1979-1993

Year	September			October			Total (Sep-Oct)		
	Hours	BH	WPUE	Hours	BH	WPUE	Hours	BH	WPUE
1979	51.80	60	1.16	79.99	130	1.63	131.79	190	1.44
1980[2]	76.41	30	0.39	50.72	12	0.24	127.13	42	0.33
1981	70.28	231	3.29	46.00	54	1.17	116.28	285	2.45
1982	77.91	283	3.63	35.19	29	0.82	113.10	312	2.76
1983[2]	101.73	72	0.71	41.48	17	0.41	143.21	89	0.62
1984[3]	73.64	216	2.93	63.49	85	1.34	137.13	301	2.19
1985[3]	67.39	52	0.77	58.22	57	0.98	125.61	109	0.87
1986	100.21	65	0.65	51.96	35	0.67	152.17	100	0.66
1987	90.07	61	0.68	77.07	76	0.99	167.14	137	0.82
1988[2]	64.96	21	0.32	55.49	19	0.34	120.45	40	0.33
1989	69.84	141	2.02	38.61	149	3.86	108.45	290	2.67
1990	54.85	401	7.31	41.37	77	1.86	96.22	478	4.97
1991[2]	38.36	9	0.23	51.13	40	0.78	89.49	49	0.55
1992[3]	104.28	63	0.60	90.52	234	2.59	194.80	297	1.52
1993	87.33	217	2.48	77.89	136	1.75	165.22	353	2.14

Table 15
Relative Abundance (WPUE) of Bowhead Whales within the Primary Study Area (Survey Blocks 1-12) during September and October[1], by Year and General Ice Coverage, 1979-1993
(Continued)

Ice Coverage	September			October			Total (Sep-Oct)		
	Hours	BH	WPUE	Hours	BH	WPUE	Hours	BH	WPUE
Heavy Ice Years[2](Σ)	281.46	132	0.47	198.82	88	0.44	480.28	220	0.46
Moderate Ice Years[3](Σ)	245.31	331	1.35	212.23	376	1.77	457.54	707	1.55
Light Ice Years (Σ)	602.29	1,459	2.42	448.08	686	1.53	1,050.37	2,145	2.04

1 After Ljungblad et al. (1987), Moore and Clarke (1992), and Treacy (1988, 1989, 1990, 1991, 1992, 1993).
2 1980, 1983, 1988, and 1991 were considered years of heavy ice coverage.
3 1984, 1985, and 1992 were considered years of moderate ice coverage.

overlaps that for moderate ice years ($\bar{x}$ = 1.53, SD = 0.66, n = 3). Likewise, a nonparametric Tukey-type test (Zar, 1984) for comparing unequal sample sizes showed that while relative abundance in light ice years was significantly different ($p < 0.05$) from that in heavy ice years, neither of these two categories was significantly different from relative abundance in moderate ice years. A separate comparison of ice concentrations at the location of bowhead sightings (1981-1986) with the observability of whales showed that sighting distance was significantly affected by local ice cover only in 1982 and 1983 (Ljungblad et al., 1987).

The relative abundance of bowhead whales was compared between years to obtain a rough indication of any temporal trends. In order to control against extreme variation in ice severity between years, the WPUE was compared during September, October, and both months combined (Table 15) for only those years of light ice (1979, 1981, 1982, 1986, 1987, 1989, 1990, and 1993). The data showed weak tendencies for bowhead relative abundance to increase from 1979 through 1993, but the correlations were not statistically significant.

E. Management Use of Real-Time Field Information

The MMS issues various types of permits to industry for gas and oil exploration, including vessel geophysical permits for on-water exploration using an array of deep-seismic air guns; vessel geological-geophysical permits for shallow seismic exploration using an airgun; on-ice geophysical permits using VIBROSEIS technology; both vessel and on-ice geological permits for obtaining core samples; and permits to drill for gas and oil.

During 1993, MMS issued four on-ice geophysical (VIBROSEIS) permits to industry for seismic exploration in the central to eastern portions of the Alaskan Beaufort Sea. These explorations were permitted from the first part of January through the end of May, prior to the fall migration of bowhead whales. Two vessel geophysical permits were issued in the same general area for mid-July through the end of August. Preliminary activities for site clearance were conducted at the Wild Weasel Prospect from 18 July through 24 August 1993.

In order to prevent potential operational effects on subsistence whaling, any geophysical vessel explorations permitted during the fall follow stringent restrictions--including a provision to stop seismic operations when whales were visible from the vessel--as the bowhead whale migration progressed through the area of operations. For explorations that occurred during the fall, daily summaries of survey information were transferred from the field to Anchorage for use by MMS Resource Evaluation and by NMFS in implementing areawide permit restrictions on high-energy seismic operations during periods of limited visibility.

ARCO Alaska Inc. conducted drilling operations north of Camden Bay at the Kuvlum 2 and Kuvlum 3 sites, both part of the Kuvlum Prospect, and at the Wild Weasel Prospect using the semisubmersible drilling barge *Kulluk*, supported by three ice-management vessels. The maximum hull diameter of this circular floating structure is 80.8 m and the maximum hull depth is 18.5 m. The *Kulluk* has a 12-point mooring system employing anchor wires that are 8.9 centimeters in diameter. This conical drilling unit was on location at Kuvlum 2 (70°18.6´N. latitude, 145°32.3´W. longitude) on 18 July, with drilling from 28 July through 29 August 1993. It was on location at Kuvlum 3 (70°19.6´ N. latitude, 145°24.2´W. longitude) on 30 August, with drilling from 9 September through 5 October 1993. It was on location at Wild Weasel (70°13.4´N. latitude, 145°30.0´W. longitude) on 6 October, with drilling from 13 October through 9 November 1993. The Wild Weasel well was abandoned on 10 November 1993.

Sightings of bowhead whales in the general study area, including those in the vicinity of drill sites, are shown for each bimonthly period of the Fall-1993 survey in Figures 17 through 21. The closest sighting of a bowhead whale to a drill site was noted on 4 September 1993 (Appendix B: Flight 3) at a distance of 16.3 km west-southwest of the operational *Kulluk* drilling barge. This adult whale was swimming at a 260° compass heading in 0-percent ice when observed.

Daily summaries of field information from this survey, and other arctic surveys being conducted concurrently, were transferred by the MMS Team Leader to MMS Field Operations in Anchorage. The MMS and NMFS reviewed daily reports to determine the distributional patterns of bowheads in the vicinity of oil and gas industry activities and the timing of the bowhead whale migration, especially the "end of the migration" past the Kuvlum drill site.

Project ice data were transmitted daily to the U.S. Navy-NOAA Joint Ice Center for their use in ground-truthing satellite imagery. Sighting data were used by several management groups to monitor the progress of the overall fall migration of bowhead whales across the Alaskan Beaufort Sea and to determine the position of their overall migratory corridor relative to shore. Data from previous surveys continue to be used by MMS in writing Environmental Impact Statements and Environmental Assessments and in interpreting the results of site-specific studies.

F. Field Coordinations

Information summaries were provided to various requesting agencies and private-sector organizations, including the USDOD Naval Polar Oceanography Center, Washington, D.C.; Alaska Eskimo Whaling Commission, Barrow, Alaska; and an ARCO Alaska Inc.-funded study, conducted by Coastal and Offshore Pacific Corporation, that was monitoring marine mammals in the vicinity of the Kuvlum drill site.

Aircraft safety was coordinated on a daily basis with the ARCO Alaska Inc.-funded study to avoid simultaneous sampling in the same area. We also coordinated with NMFS, Anchorage, Alaska; North Slope Borough, Barrow, Alaska; and an oil industry/whalers' conflict-avoidance group, Deadhorse, Alaska.

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APPENDIX A

BOWHEAD WHALE DENSITIES

BOWHEAD WHALE DENSITIES

This appendix presents estimated bowhead whale densities in the Beaufort Sea for the period 1 September through 28 October 1993. Present survey goals do not include estimation of absolute population abundance; therefore, raw density values found in this report were not adjusted to account for submergence of whales, sighting variability, etc., and are presented only for relative visual comparison with similarly calculated values from previous survey reports. Also, sample sizes for determining density in individual survey blocks were considered too small to stratify by category (sea state, ice cover, etc.) or to make statistical correlations having real biological significance.

METHODS

A computer program--DENSITY--was used to calculate raw density estimates for survey blocks previously shown for the Beaufort Sea (Fig. 1). The program was based on strip-transect methodologies that use only sightings made on random-transect legs (Estes and Gilbert, 1978) and that were within a predetermined distance from the aircraft (Hayne, 1949). Distance from the transect line was calculated trigonometrically from the altitude of the survey plane at the time of sighting and the clinometer angle recorded for each initial sighting location. Only endangered whale sightings within 1 km of random-transect legs were used to derive density estimates. The number of sightings made from project aircraft decreased markedly much beyond that distance, with 69 percent of sightings from the Twin Otter made within 1 km of the trackline. The basic assumptions for use of this formula, and the degree to which these assumptions were met in the Fall-1993 and previous MMS-funded arctic whale surveys, are incorporated by reference (Ljungblad et al., 1987: Appendix B).

RESULTS

Densities by survey block were estimated as the number of bowhead whales per 100 km^2 (Table A-1).

During the first half of September, over 10 percent of the area was surveyed for Blocks 1, 2, 5, 7, and 12. Of these blocks, no bowheads were observed in Blocks 2 and 7 within 1 km of the randomly generated transect line, for estimated densities of 0.00 whales per 100 km^2. Eight bowheads were observed in Block 5, for an estimated density of 0.34. Two bowheads were observed in Blocks 1 and 12, for an estimated density of 0.17 and 0.12, respectively. An additional 8 bowheads were observed in Block 4, where only 9.97 percent of the block was surveyed, for an estimated density of 1.40. No bowhead whales were observed within 1 km of the transect line in other blocks during this period (Table A-1).

During the second half of September, over 10 percent of the area was surveyed for Blocks 1, 2, 3, 6, and 11. Of these blocks, no bowheads were observed in Blocks 2, 6, and 11 within 1 km of the randomly generated transect line, for estimated densities of 0.00 whales per 100 km^2. Eight bowheads were observed in Block 3, for an estimated density of 0.35. Six bowheads were observed in Block 1, for an estimated density of 0.35. Three bowhead whales were observed within 1 km of the transect line in other blocks during this period (Table A-1).

During the first half of October, over 10 percent of the area was surveyed for Blocks 1, 4, and 6. Of these blocks, 7 bowheads were observed in Block 4 within 1 km of the randomly generated transect line, for an estimated density of 0.32 whales per 100 km^2. Four bowheads were observed in Block 1, for an estimated density of 0.14. Two bowheads were observed in Block 6, for an estimated density of 0.09. An additional 12 bowheads were observed in Block 5, where only 9.40 percent of the block was surveyed, for an estimated density of 1.35. No bowhead whales were observed within 1 km of the transect line in other blocks during this period.

From 16 through 23 October, over 10 percent of the area was surveyed for Blocks 2 and 12. Nine bowheads were observed in Block 12 within 1 km of the randomly generated transect line, for an estimated

Table A-1
Semimonthly Estimates of Bowhead Whale Densities, by Survey Block, Fall 1993
(strip width = 2 km)

Block No. (by Semi-monthly Period)	Block Area (km^2)	Transect Distance (km)	Percent of Area Surveyed	Transect Time (hr)	Percent of Total Time	No. of Transects Flown	No. of Whales Observed	Density (Whales/ 100 km^2)
1-15 Sep								
1	10,222	574	11.24	2.53	13.01	13	2	0.17
2	6,672	368	11.03	1.64	8.44	7	0	0.00
3	11,475	231	4.02	1.00	5.12	3	0	0.00
4	5,714	285	9.97	1.41	7.27	9	8	1.40
5	9,481	1,192	25.15	5.33	27.40	19	8	0.34
6	8,109	1	0.02	0.00	0.02	1	0	0.00
7	8,109	515	12.70	2.33	12.00	8	0	0.00
8	9,753	93	1.91	0.39	1.99	2	0	0.00
10	10,358	3	0.05	0.01	0.05	2	0	0.00
11	10,358	149	2.88	0.66	3.41	3	0	0.00
12	11,163	853	15.28	4.11	21.12	11	2	0.12
12N	11,453	3	0.06	0.02	0.13	6	0	0.00
16-30 Sep								
1	10,222	868	16.99	3.98	22.01	16	6	0.35
2	6,672	406	12.17	1.84	10.17	12	0	0.00
3	11,475	1,146	19.97	5.08	28.12	17	8	0.35
4	5,714	260	9.08	1.27	7.05	6	1	0.19
5	9,481	223	4.71	1.13	6.24	3	2	0.45
6	8,109	443	10.92	2.05	11.36	6	0	0.00
7	8,109	1	0.03	0.01	0.03	1	0	0.00
9	9,753	3	0.06	0.02	0.09	1	0	0.00
10	10,358	3	0.05	0.01	0.06	4	0	0.00
11	10,358	601	11.59	2.69	14.86	9	0	0.00

Table A-1
Semimonthly Estimates of Bowhead Whale Densities, by Survey Block, Fall 1993
(strip width = 2 km)
(Continued)

Block No. (by Semimonthly Period)	Block Area (km^2)	Transect Distance (km)	Percent of Area Surveyed	Transect Time (hr)	Percent of Total Time	No. of Transects Flown	No. of Whales Observed	Density (Whales/ 100 km^2)
1-15 Oct								
1	10,222	1,422	27.83	6.11	26.33	28	4	0.14
2	6,672	148	4.42	0.62	2.66	5	0	0.00
3	11,475	513	8.95	2.30	9.92	10	1	0.10
4	5,714	1,099	38.45	4.65	20.02	25	7	0.32
5	9,481	446	9.40	1.84	7.94	6	12	1.35
6	8,109	1,106	27.29	4.67	20.10	17	2	0.09
7	8,109	147	3.62	0.64	2.75	2	0	0.00
8	9,753	92	1.89	0.40	1.72	2	0	0.00
9	9,753	1	0.01	0.00	0.01	1	0	0.00
10	10,358	1	0.01	0.00	0.01	1	0	0.00
11	10,358	442	8.54	1.98	8.53	6	0	0.00
16-28 Oct								
1	10,222	441	8.62	1.97	14.61	9	0	0.00
2	6,672	423	12.68	1.92	14.26	9	1	0.12
3	11,475	89	1.55	0.36	2.67	2	1	0.56
4	5,714	175	6.11	0.82	6.07	6	1	0.29
5	9,481	377	7.96	1.79	13.31	6	0	0.00
7	8,109	9	0.22	0.04	0.32	1	0	0.00
11	10,358	75	1.44	0.34	2.51	2	0	0.00
12	11,163	1,329	23.80	6.21	46.21	18	9	0.34
12N	11,453	0	0.01	0.00	0.01	2	0	0.00

density of 0.34 whales per 100 km^2. One bowhead was observed in Block 2, for an estimated density of 0.12. Two bowhead whales were observed within 1 km of the transect line in other blocks during this period.

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APPENDIX B

DAILY FLIGHT SUMMARIES

DAILY FLIGHT SUMMARIES

This appendix consists of maps for Flights 1 through 41, depicting aerial surveys flown over the study area from 1 September through 28 October 1993 aboard the Twin Otter aircraft. Daily maps show survey tracks and the initial position of marine mammal sightings.

A comparison of daily flight maps can be made on a visual basis over the period of the field season to evaluate ongoing patterns of marine mammal distribution and aircraft coverage. Each map shows the flight track as a line drawn through position updates recorded on the aircraft computer system. Each animal sighting is marked with a species symbol on the flight-track plot. The symbols used can be keyed out using the species legend found on each map. Positional and other data for each sighting of bowhead whales are summarized in Table B-1.

Table B-1
Selected Sighting Data for Bowhead Whales Observed, Fall 1993
(Page 1 of 7)

Flight No.	Day	Total Whales	No. of Calves	Latitude (North)	Longitude (West)	Sighting Cue	Behavior	Compass Heading	Ice (%)	Sea State	Depth (m)
1	1 Sep	1	0	69°59.7′	140°42.0′	blow	swim	210°	0	2	46
1	1 Sep	1	0	69°52.4′	141°45.1′	body	swim	210°	2	2	22
1	1 Sep	3	0	70°13.0′	143°15.7′	splash	dive	260°	0	2	26
1	1 Sep	1	0	70°12.7′	143°07.1′	body	swim	220°	0	2	29
1	1 Sep	1	0	70°13.8′	143°11.9′	body	breach	80°	0	2	26
1	1 Sep	1	0	70°19.3′	144°18.0′	splash	swim	270°	0	2	35
1	1 Sep	1	0	70°19.1′	144°15.3′	body	swim	[1]	0	2	35
1	1 Sep	2	0	70°19.3′	144°14.9′	body	swim	210°	0	2	35
1	1 Sep	1	0	70°16.4′	144°42.4′	body	rest	190°	0	2	33
1	1 Sep	2	0	70°16.4′	144°47.2′	body	mill	[1]	0	2	33
3	4 Sep	1	0	70°20.0′	147°10.4′	body	swim	70°	0	3	9
3	4 Sep	1	0	69°55.4′	142°06.1′	splash	dive	210°	1	2	18
3	4 Sep	2	0	69°55.7′	142°03.1′	body	swim	220°	1	2	18
3	4 Sep	2	0	69°55.2′	141°59.8′	body	swim	220°	1	2	24
3	4 Sep	1	0	69°56.2′	142°07.3′	body	swim	220°	1	2	18
3	4 Sep	1	0	70°01.1′	142°20.5′	body	rest	205°	1	2	18
3	4 Sep	1	0	70°07.2′	142°49.2′	splash	swim	260°	1	4	20
3	4 Sep	1	0	70°08.5′	142°48.3′	body	swim	240°	1	4	20
3	4 Sep	1	0	70°10.4′	142°48.8′	body	swim	200°	0	4	33
3	4 Sep	2	0	70°09.8′	143°03.9′	body	mill	[1]	0	5	18
3	4 Sep	1	0	70°16.2′	144°15.4′	splash	swim	100°	0	3	37
3	4 Sep	1	0	70°15.5′	144°17.7′	body	swim	100°	0	2	37
3	4 Sep	2	0	70°15.2′	144°41.3′	body	dive	210°	0	2	33
3	4 Sep	1	0	70°13.0′	144°40.1′	body	swim	260°	0	2	26
3	4 Sep	1	0	70°04.5′	145°03.9′	body	swim	50°	0	2	9
3	4 Sep	2	0	70°23.4′	145°53.3′	blow	swim	140°	0	4	27
3	4 Sep	1	0	70°16.6′	145°48.7′	splash	swim	260°	0	4	24
3	4 Sep	1	0	70°15.7′	145°48.4′	splash	swim	120°	0	4	24
3	4 Sep	2	0	70°15.6′	145°51.6′	body	mill	[1]	0	4	18
3	4 Sep	1	0	70°24.3′	146°23.3′	body	swim	240°	0	4	37
3	4 Sep	5	0	70°25.7′	146°22.9′	body	mill	[1]	0	4	37
3	4 Sep	1	0	70°26.9′	146°21.2′	body	swim	190°	0	4	37
6	8 Sep	4	0	70°10.8′	144°03.4′	body	mill	230°	0	2	16
6	8 Sep	1	0	70°12.4′	143°21.1′	splash	swim	260°	0	3	13
6	8 Sep	2	1	69°59.5′	141°53.1′	body	cow with calf	120°	0	3	29

Table B-1
Selected Sighting Data for Bowhead Whales Observed, Fall 1993
(Page 2 of 7)

Flight No.	Day	Total Whales	No. of Calves	Latitude (North)	Longitude (West)	Sighting Cue	Behavior	Compass Heading	Ice (%)	Sea State	Depth (m)
6	8 Sep	4	0	70°18.9′	142°13.3′	splash	swim	40°	0	2	49
6	8 Sep	1	0	70°21.0′	146°44.1′	body	swim	240°	0	2	13
7	9 Sep	1	0	70°17.9′	146°12.4′	body	swim	160°	0	3	15
7	9 Sep	2	0	70°30.9′	147°14.3′	splash	swim	280°	0	4	24
7	9 Sep	1	0	70°25.7′	147°12.3′	blow	dive	[1]	0	3	15
7	9 Sep	1	0	70°24.6′	146°50.3′	splash	swim	255°	0	3	18
7	9 Sep	1	0	70°23.8′	146°45.8′	body	swim	350°	0	3	13
7	9 Sep	1	0	70°23.2′	146°42.4′	splash	dive	[1]	0	3	13
7	9 Sep	1	0	70°18.4′	146°11.1′	splash	swim	270°	0	3	22
7	9 Sep	1	0	70°28.9′	147°17.6′	splash	swim	300°	0	2	18
7	9 Sep	1	0	70°31.2′	147°18.1′	splash	swim	300°	0	2	24
7	9 Sep	2	0	70°39.0′	148°19.4′	splash	swim	180°	0	3	26
10	12 Sep	4	0	71°30.1′	156°20.9′	splash	slap	270°	0	4	157
10	12 Sep	1	0	71°30.3′	156°26.3′	splash	slap	240°	0	4	157
10	12 Sep	2	0	71°30.1′	156°20.8′	body	swim	240°	0	4	157
10	12 Sep	1	0	71°29.2′	156°30.3′	body	dive	240°	0	4	73
10	12 Sep	1	0	71°28.8′	156°32.8′	body	swim	240°	0	4	73
10	12 Sep	1	0	71°28.5′	156°33.9′	blow	swim	250°	0	4	73
10	12 Sep	1	0	71°25.9′	156°20.1′	splash	dive	270°	0	5	9
10	12 Sep	2	0	71°29.0′	155°43.1′	body	swim	220°	0	4	16
12	15 Sep	1	0	69°52.2′	140°48.4′	body	rest	300°	0	1	37
12	15 Sep	1	0	70°05.8′	141°36.8′	splash	swim	230°	0	1	40
12	15 Sep	1	0	70°18.6′	143°06.9′	blow	swim	210°	0	2	51
14	19 Sep	1	0	70°37.1′	146°54.8′	splash	swim	90°	0	3	38
14	19 Sep	1	0	70°19.3′	146°05.7′	body	swim	270°	0	4	22
14	19 Sep	1	0	70°35.7′	146°11.1′	splash	swim	220°	0	4	37
14	19 Sep	1	0	70°41.5′	146°41.1′	body	dive	240°	0	2	37
14	19 Sep	1	0	70°34.3′	146°39.5′	splash	swim	360°	0	2	38
14	19 Sep	1	0	70°45.6′	147°22.5′	body	underwater blow	270°	0	2	40
14	19 Sep	1	0	70°48.1′	147°44.8′	body	swim	270°	0	3	40
14	19 Sep	1	0	70°58.5′	148°27.7′	splash	swim	280°	0	3	29
14	19 Sep	1	0	70°59.4′	148°35.6′	splash	swim	240°	0	3	26
14	19 Sep	1	0	71°01.9′	148°26.5′	splash	swim	240°	0	3	29
15	20 Sep	11	0	70°40.7′	150°48.0′	body	mill	[1]	0	2	15
15	20 Sep	1	0	70°40.7′	150°48.0′	body	swim	50°	0	2	15

Table B-1
Selected Sighting Data for Bowhead Whales Observed, Fall 1993
(Page 3 of 7)

Flight No.	Day	Total Whales	No. of Calves	Latitude (North)	Longitude (West)	Sighting Cue	Behavior	Compass Heading	Ice (%)	Sea State	Depth (m)
15	20 Sep	2	0	70°40.3′	150°45.2′	body	swim	[1]	0	2	15
15	20 Sep	1	0	70°40.8′	150°44.2′	body	swim	[1]	0	2	15
15	20 Sep	1	0	70°40.8′	150°44.8′	body	swim	[1]	0	2	15
15	20 Sep	1	0	70°40.3′	150°45.2′	body	swim	230°	0	2	15
15	20 Sep	1	0	70°40.2′	150°44.8′	body	swim	[1]	0	2	15
15	20 Sep	2	0	70°40.5′	150°44.6′	body	swim	30°	0	2	15
15	20 Sep	1	0	70°40.7′	150°46.1′	body	swim	190°	0	2	15
15	20 Sep	1	0	70°40.5′	150°44.4′	body	swim	150°	0	2	15
15	20 Sep	1	0	70°58.3′	151°19.2′	body	swim	60°	0	4	18
15	20 Sep	1	0	70°57.4′	151°18.3′	body	swim	30°	0	4	18
15	20 Sep	1	0	71°07.4′	151°30.9′	blow	swim	270°	0	4	22
15	20 Sep	1	0	71°06.5′	151°26.8′	splash	swim	270°	0	4	20
15	20 Sep	1	0	71°03.3′	151°00.5′	blow	swim	260°	0	4	18
15	20 Sep	1	0	70°47.9′	149°41.9′	splash	swim	270°	0	2	15
15	20 Sep	1	0	70°54.8′	149°23.7′	blow	swim	240°	0	2	22
15	20 Sep	1	0	70°54.7′	148°21.6′	body	swim	240°	0	3	38
15	20 Sep	2	1	70°58.9′	148°17.8′	body	cow with calf	220°	0	3	37
15	20 Sep	1	0	70°36.9′	147°37.4′	body	swim	150°	0	5	38
16	22 Sep	1	0	71°07.8′	153°20.8′	body	swim	280°	0	6	27
16	22 Sep	1	0	71°21.3′	154°33.8′	body	swim	60°	0	7	22
17	24 Sep	2	0	70°19.0′	146°51.9′	splash	swim	250°	0	1	11
17	24 Sep	2	0	70°18.2′	146°51.3′	body	swim	240°	0	1	11
17	24 Sep	1	0	70°18.6′	146°48.0′	[1]	swim	270°	0	1	15
17	24 Sep	3	0	70°18.6′	146°46.1′	body	mill	[1]	0	1	15
17	24 Sep	1	0	70°18.3′	146°47.8′	body	swim	[1]	0	1	15
17	24 Sep	1	0	70°19.2′	146°45.6′	[1]	swim	[1]	0	1	15
17	24 Sep	1	0	70°20.4′	146°34.2′	body	swim	180°	0	2	16
17	24 Sep	1	0	70°15.4′	142°47.5′	splash	swim	170°	0	2	44
17	24 Sep	1	0	70°15.3′	142°48.0′	body	swim	[1]	0	2	44
17	24 Sep	1	0	70°16.1′	142°47.5′	splash	swim	180°	0	2	44
17	24 Sep	1	0	70°15.3′	142°46.3′	splash	swim	[1]	0	2	44
17	24 Sep	1	0	70°11.4′	142°31.5′	splash	swim	350°	0	2	29
17	24 Sep	1	0	70°09.8′	142°26.2′	body	swim	80°	0	2	33
17	24 Sep	1	0	69°58.9′	141°19.6′	blow	swim	190°	0	3	40
17	24 Sep	1	0	70°07.8′	142°09.9′	body	swim	250°	0	2	38

Table B-1
Selected Sighting Data for Bowhead Whales Observed, Fall 1993
(Page 4 of 7)

Flight No.	Day	Total Whales	No. of Calves	Latitude (North)	Longitude (West)	Sighting Cue	Behavior	Compass Heading	Ice (%)	Sea State	Depth (m)
17	24 Sep	1	0	70°19.2′	143°09.4′	body	swim	270°	0	5	51
17	24 Sep	1	0	70°28.3′	144°15.3′	splash	swim	250°	0	2	51
17	24 Sep	1	0	70°35.5′	147°20.2′	splash	dive	220°	0	2	31
19	28 Sep	1	0	70°51.6′	151°00.5′	body	swim	70°	0	4	15
19	28 Sep	1	0	70°54.2′	151°03.0′	body	swim	210°	0	4	15
19	28 Sep	1	0	70°54.4′	151°04.4′	blow	swim	120°	0	3	15
19	28 Sep	3	0	70°51.8′	151°02.2′	body	swim	270°	0	3	15
19	28 Sep	1	0	70°52.1′	151°02.2′	blow	swim	170°	0	3	15
19	28 Sep	1	0	70°30.6′	148°23.3′	body	dive	50°	0	3	15
20	29 Sep	1	0	70°41.5′	149°20.1′	body	swim	20°	0	4	13
20	29 Sep	23	0	70°41.8′	149°29.0′	body	mill	[1]	0	4	13
20	29 Sep	1	0	70°41.3′	149°26.5′	body	swim	[1]	0	4	13
20	29 Sep	1	0	70°41.7′	149°29.7′	body	dive	200°	0	4	13
20	29 Sep	2	0	70°41.0′	149°27.4′	body	swim	290°	0	4	13
20	29 Sep	2	0	70°42.1′	149°27.3′	body	swim	300°	0	4	11
20	29 Sep	1	0	70°42.5′	149°31.5′	body	swim	210°	0	4	9
20	29 Sep	2	0	70°41.2′	149°38.8′	body	swim	50°	0	4	11
20	29 Sep	2	0	70°41.3′	149°44.4′	body	swim	230°	0	4	15
20	29 Sep	1	0	70°41.4′	149°54.7′	body	swim	220°	0	3	16
20	29 Sep	5	0	70°41.8′	150°04.6′	body	swim	260°	0	3	16
20	29 Sep	1	0	70°42.5′	150°11.5′	body	swim	260°	0	3	18
20	29 Sep	2	0	70°42.8′	150°15.6′	body	swim	260°	0	3	18
20	29 Sep	2	0	70°43.4′	150°22.7′	body	swim	260°	0	3	18
20	29 Sep	2	0	70°43.7′	150°28.5′	body	swim	250°	0	3	18
20	29 Sep	1	0	71°00.3′	153°36.3′	blow	swim	150°	0	3	13
20	29 Sep	1	0	71°02.5′	153°36.7′	splash	dive	[1]	0	3	13
20	29 Sep	1	0	71°07.0′	152°15.2′	splash	swim	250°	0	2	20
20	29 Sep	1	0	70°59.6′	151°46.6′	body	swim	300°	0	2	13
20	29 Sep	1	0	70°49.1′	150°43.9′	splash	swim	270°	0	2	15
20	29 Sep	1	0	70°41.1′	150°25.4′	body	dive	330°	0	2	15
20	29 Sep	1	0	70°40.1′	150°24.3′	blow	swim	310°	0	2	15
20	29 Sep	1	0	70°37.4′	150°24.0′	body	swim	120°	0	2	13
22	2 Oct	1	0	71°01.1′	151°12.2′	body	swim	[1]	0	6	20
23	3 Oct	1	0	70°08.8′	144°58.6′	body	swim	240°	0	3	18
23	3 Oct	1	0	70°09.1′	144°48.9′	body	swim	10°	0	3	24

Table B-1
Selected Sighting Data for Bowhead Whales Observed, Fall 1993
(Page 5 of 7)

Flight No.	Day	Total Whales	No. of Calves	Latitude (North)	Longitude (West)	Sighting Cue	Behavior	Compass Heading	Ice (%)	Sea State	Depth (m)
23	3 Oct	3	0	70°10.1′	144°19.4′	splash	swim	230°	0	2	16
23	3 Oct	1	0	70°10.4′	144°08.6′	body	swim	45°	0	2	16
23	3 Oct	1	0	70°10.6′	144°03.3′	body	swim	100°	0	2	16
23	3 Oct	1	0	70°12.2′	143°35.7′	splash	dive	[1]	0	3	16
23	3 Oct	1	0	70°11.6′	143°25.4′	splash	swim	70°	0	3	9
24	4 Oct	1	0	70°46.6′	149°51.5′	body	swim	270°	0	7	13
24	4 Oct	1	0	70°46.0′	149°47.2′	body	swim	100°	0	7	15
24	4 Oct	1	0	70°41.4′	149°08.0′	body	swim	75°	0	6	18
24	4 Oct	1	0	70°40.4′	148°59.8′	body	swim	260°	0	7	20
25	5 Oct	2	0	70°21.7′	146°55.7′	body	swim	290°	0	5	13
25	5 Oct	1	0	70°20.2′	146°51.7′	body	swim	[1]	0	5	11
25	5 Oct	1	0	70°29.7′	147°53.1′	body	swim	240°	0	4	9
25	5 Oct	1	0	70°41.7′	148°59.1′	body	swim	210°	0	4	20
25	5 Oct	3	0	70°49.4′	149°54.1′	body	swim	270°	0	3	15
25	5 Oct	1	0	70°49.6′	149°56.2′	body	swim	270°	0	3	15
25	5 Oct	3	0	70°50.3′	150°05.3′	body	mill	[1]	0	3	15
25	5 Oct	1	0	70°50.6′	150°08.9′	body	swim	210°	0	3	15
25	5 Oct	1	0	70°59.3′	151°33.1′	body	swim	300°	0	3	16
25	5 Oct	1	0	71°04.2′	153°40.5′	splash	dive	60°	0	3	16
25	5 Oct	2	0	71°08.7′	153°06.1′	splash	swim	220°	0	3	18
25	5 Oct	1	0	71°06.9′	153°04.9′	splash	swim	210°	0	3	18
25	5 Oct	1	0	70°52.1′	150°16.2′	body	swim	160°	0	6	18
25	5 Oct	2	0	70°51.1′	150°15.9′	body	swim	200°	0	6	18
26	6 Oct	1	0	70°41.8′	149°56.0′	body	dive	250°	0	4	16
27	7 Oct	1	0	70°14.4′	144°07.1′	body	swim	240°	0	2	29
27	7 Oct	1	0	70°28.2′	144°09.4′	body	swim	150°	0	2	53
27	7 Oct	1	0	70°29.0′	144°09.7′	body	dive	320°	0	2	53
27	7 Oct	2	0	70°13.5′	143°39.4′	body	swim	270°	0	2	16
27	7 Oct	2	0	70°11.6′	143°38.8′	body	mill	[1]	0	2	16
27	7 Oct	1	0	70°26.9′	144°41.5′	body	swim	280°	0	2	42
28	8 Oct	1	0	70°08.7′	142°58.4′	splash	swim	75°	0	2	18
28	8 Oct	1	0	70°23.8′	142°43.1′	splash	swim	65°	0	3	59
28	8 Oct	1	0	70°23.3′	142°43.0′	body	swim	270°	0	3	59
28	8 Oct	1	0	70°20.2′	142°42.3′	[1]	swim	140°	0	3	48
28	8 Oct	1	0	70°19.1′	142°42.2′	body	[1]	[1]	0	3	48

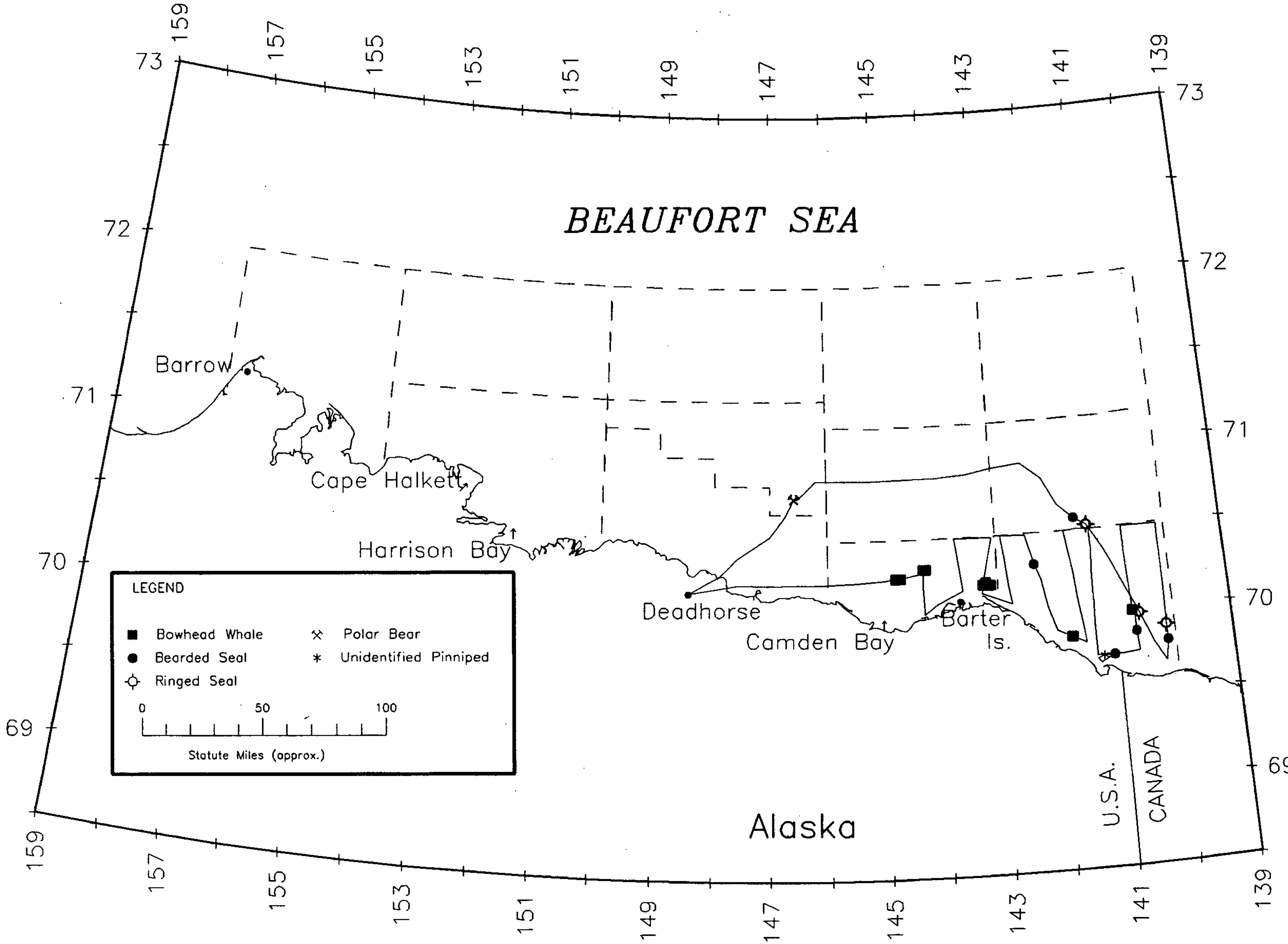
Table B-1
Selected Sighting Data for Bowhead Whales Observed, Fall 1993
(Page 6 of 7)

Flight No.	Day	Total Whales	No. of Calves	Latitude (North)	Longitude (West)	Sighting Cue	Behavior	Compass Heading	Ice (%)	Sea State	Depth (m)
28	8 Oct	1	0	70°19.0′	142°42.2′	body	swim	240°	0	3	48
28	8 Oct	1	0	70°18.8′	142°42.1′	body	[1]	[1]	0	3	48
28	8 Oct	1	0	70°18.5′	142°42.1′	body	swim	240°	0	3	48
28	8 Oct	2	0	70°18.0′	142°42.1′	blow	swim	260°	0	3	48
28	8 Oct	2	0	70°17.8′	142°42.1′	body	[1]	70°	0	3	44
28	8 Oct	1	0	70°15.6′	142°42.2′	blow	swim	120°	0	3	44
28	8 Oct	1	0	70°13.1′	142°42.8′	body	swim	280°	0	3	22
28	8 Oct	1	0	70°23.5′	143°45.5′	splash	dive	[1]	0	3	38
28	8 Oct	1	0	70°30.3′	144°10.6′	splash	swim	220°	0	3	64
28	8 Oct	2	1	70°30.2′	144°19.8′	splash	cow with calf	245°	0	3	64
28	8 Oct	1	0	70°30.3′	144°43.9′	body	swim	120°	0	3	59
29	10 Oct	1	0	70°51.6′	149°06.5′	splash	swim	230°	0	2	24
29	10 Oct	2	1	70°52.7′	148°10.7′	body	cow with calf	170°	0	3	29
29	10 Oct	1	0	70°38.7′	145°36.3′	splash	swim	[1]	0	2	48
29	10 Oct	1	0	70°44.5′	145°14.5′	splash	swim	270°	0	2	93
29	10 Oct	1	0	70°27.8′	143°22.3′	splash	swim	200°	0	3	48
29	10 Oct	1	0	70°13.3′	143°24.2′	body	swim	60°	0	4	13
30	13 Oct	1	0	70°11.9′	143°45.7′	body	swim	210°	0	2	9
30	13 Oct	1	0	70°11.9′	143°45.7′	body	swim	240°	0	2	9
30	13 Oct	2	0	70°10.6′	143°26.0′	body	mill	[1]	0	2	9
30	13 Oct	1	0	70°16.0′	143°53.9′	splash	swim	220°	0	2	26
30	13 Oct	1	0	70°50.6′	145°18.4′	splash	swim	260°	0	3	229
30	13 Oct	1	0	70°49.1′	149°43.3′	body	swim	270°	0	4	18
31	14 Oct	2	0	70°52.7′	151°19.6′	body	swim	250°	0	5	18
32	16 Oct	1	0	70°19.4′	143°16.8′	splash	swim	290°	0	3	46
34	19 Oct	1	0	71°40.7′	156°47.7′	splash	swim	260°	0	2	90
34	19 Oct	1	0	71°23.6′	155°29.3′	body	swim	30°	0	3	9
34	19 Oct	3	0	71°24.2′	155°29.0′	splash	swim	240°	0	3	18
34	19 Oct	1	0	71°24.2′	155°29.0′	body	swim	240°	0	o	18
34	19 Oct	1	0	71°24.2′	155°29.0′	splash	swim	240°	0	3	18
35	20 Oct	1	0	71°06.0′	152°40.7′	body	swim	240°	0	3	22
35	20 Oct	2	0	71°20.4′	155°02.0′	splash	swim	260°	0	3	18
35	20 Oct	1	0	71°21.8′	155°15.9′	splash	swim	340°	0	3	11
35	20 Oct	1	0	71°20.7′	155°16.8′	splash	mill	240°	0	3	16
35	20 Oct	3	0	71°19.4′	155°20.1′	splash	swim	240°	0	3	16

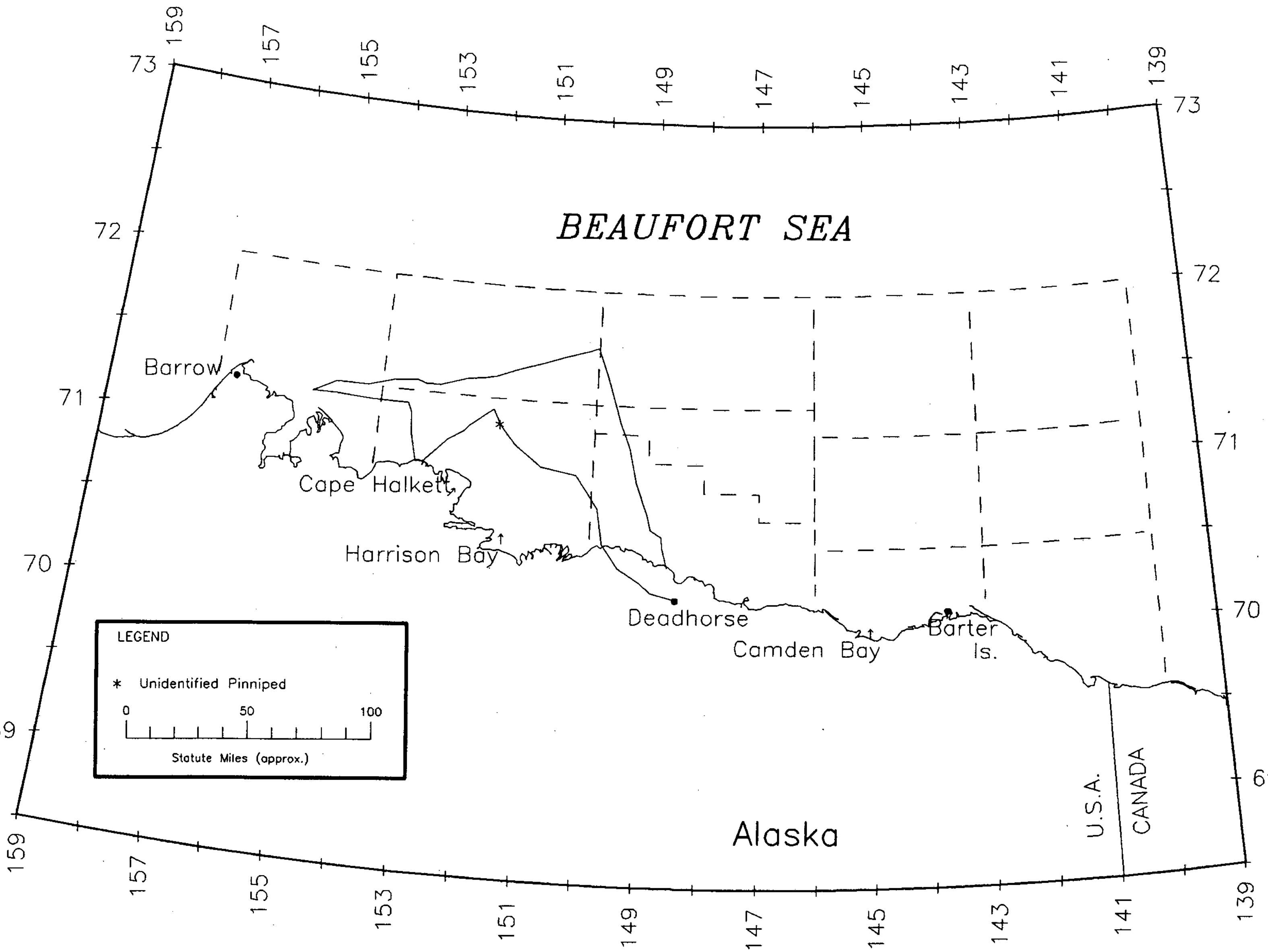
Table B-1
Selected Sighting Data for Bowhead Whales Observed, Fall 1993
(Page 7 of 7)

Flight No.	Day	Total Whales	No. of Calves	Latitude (North)	Longitude (West)	Sighting Cue	Behavior	Compass Heading	Ice (%)	Sea State	Depth (m)
35	20 Oct	1	0	71°19.4′	155°20.1′	[1]	swim	270°	0	3	16
35	20 Oct	3	0	71°19.3′	155°22.7′	body	mill	[1]	0	3	13
35	20 Oct	2	0	71°19.5′	155°25.0′	splash	mill	[1]	0	3	13
35	20 Oct	1	0	71°19.7′	155°27.4′	body	swim	300°	0	3	13
35	20 Oct	1	0	71°30.0′	156°25.8′	splash	swim	300°	0	3	157
35	20 Oct	1	0	71°29.7′	156°25.9′	body	rest	[1]	0	3	126
35	20 Oct	1	0	71°26.4′	155°56.4′	splash	swim	250°	0	3	9
35	20 Oct	1	0	71°27.2′	155°54.5′	body	swim	280°	0	3	18
35	20 Oct	1	0	71°27.7′	155°53.2′	body	swim	250°	0	3	18
35	20 Oct	1	0	71°28.0′	155°52.4′	body	swim	350°	0	3	18
35	20 Oct	1	0	71°28.3′	155°51.6′	splash	swim	220°	0	3	18
35	20 Oct	5	0	71°28.8′	155°50.0′	splash	swim	220°	0	3	16
35	20 Oct	1	0	71°29.2′	155°49.1′	body	breach	[1]	0	3	16
35	20 Oct	1	0	71°29.1′	155°08.5′	splash	swim	130°	0	3	13
35	20 Oct	1	0	71°12.4′	154°42.6′	splash	swim	280°	0	3	15
35	20 Oct	1	0	71°15.9′	154°40.7′	body	[1]	40°	0	3	15
35	20 Oct	1	0	71°06.6′	153°36.5′	body	swim	230°	0	2	2
35	20 Oct	2	0	71°09.5′	153°36.9′	splash	swim	230°	0	2	16
37	22 Oct	1	0	71°01.6′	147°16.3′	splash	swim	220°	0	4	53
39	26 Oct	3	0	71°08.8′	154°18.0′	body	swim	[1]	50	4	13
39	26 Oct	3	0	71°08.8′	154°18.0′	blow	[1]	[1]	50	4	13
39	26 Oct	1	0	71°09.8′	154°20.4′	body	dive	220°	50	4	15
39	26 Oct	1	0	71°09.6′	154°12.2′	[1]	swim	90°	0	3	15
40	27 Oct	5	0	71°08.8′	154°17.8′	body	mill	80°	50	0	13
40	27 Oct	1	0	71°08.6′	154°14.3′	body	slap	[1]	60	0	13

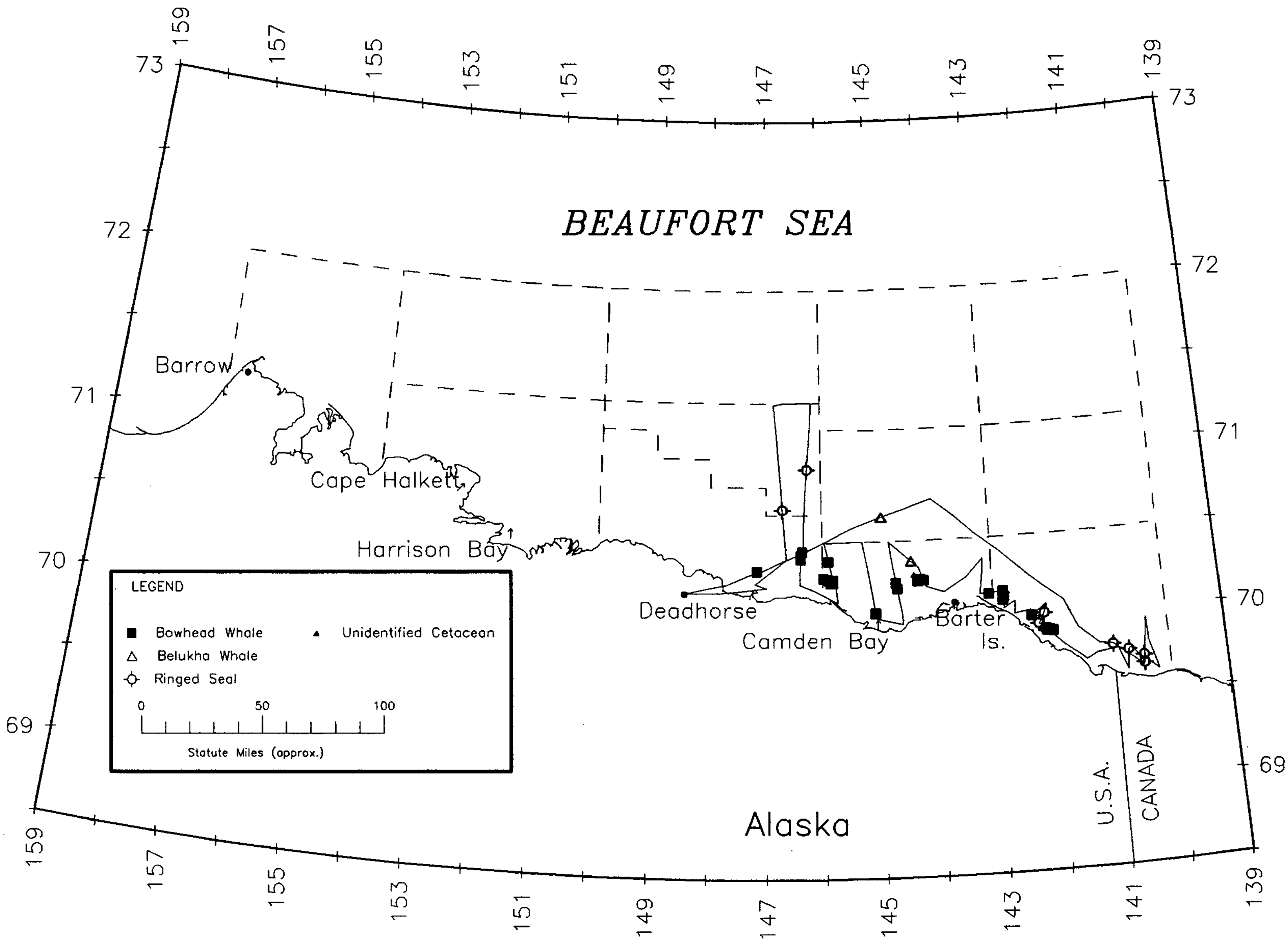
[1] Not recorded



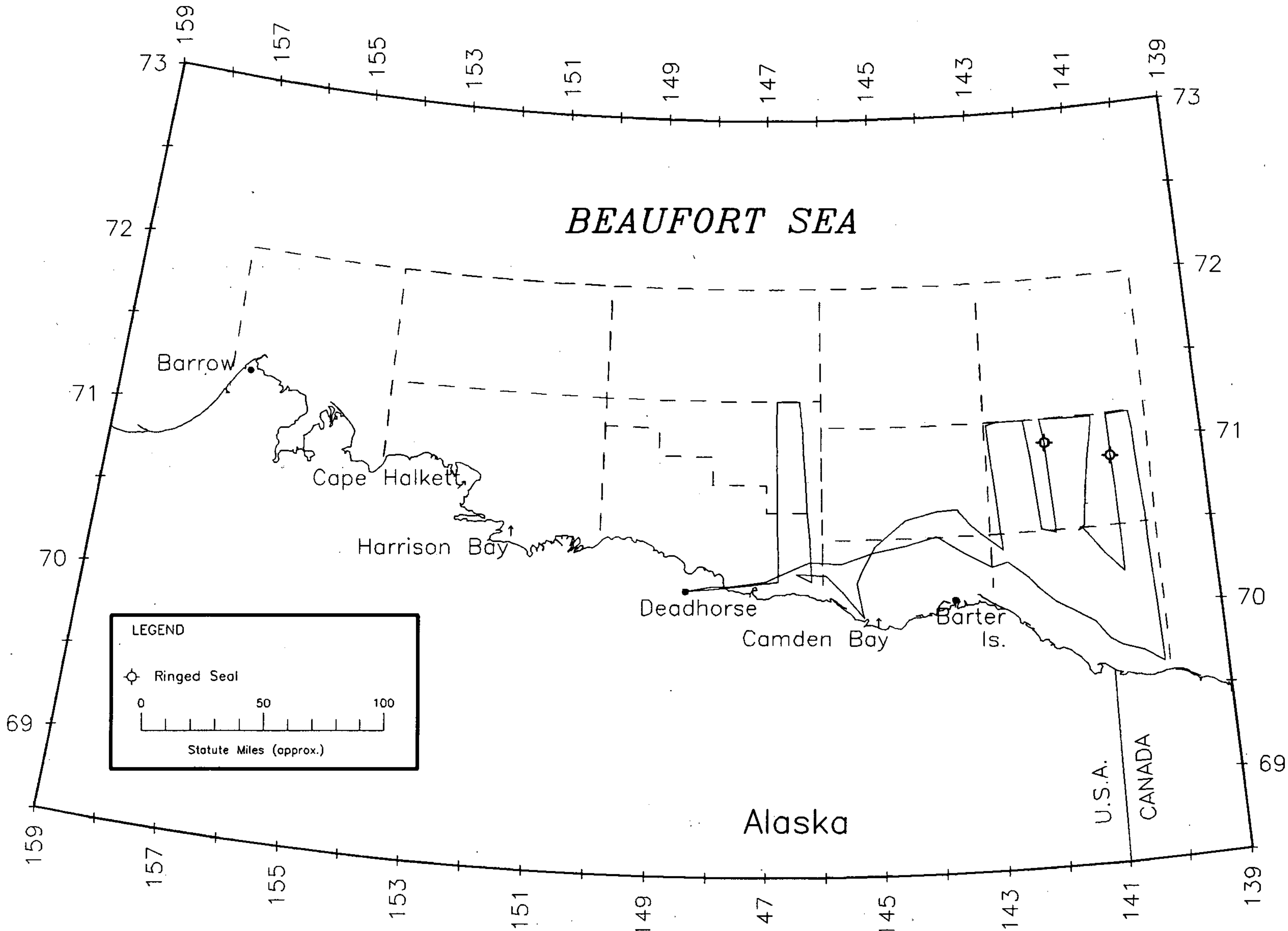
FLIGHT 1 1 September 1993
Survey Track and Sightings



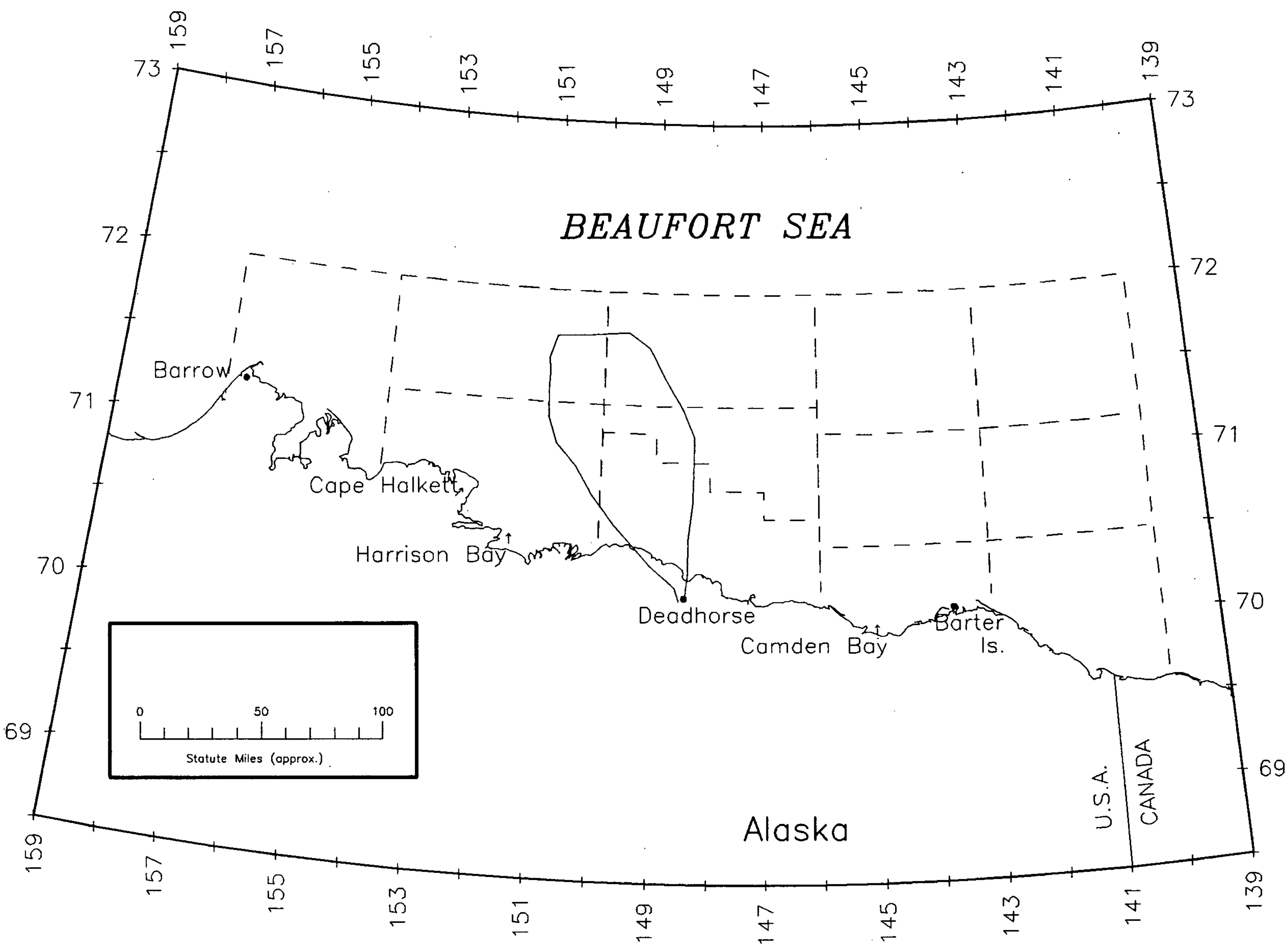
FLIGHT 2 2 September 1993
Survey Track and Sightings



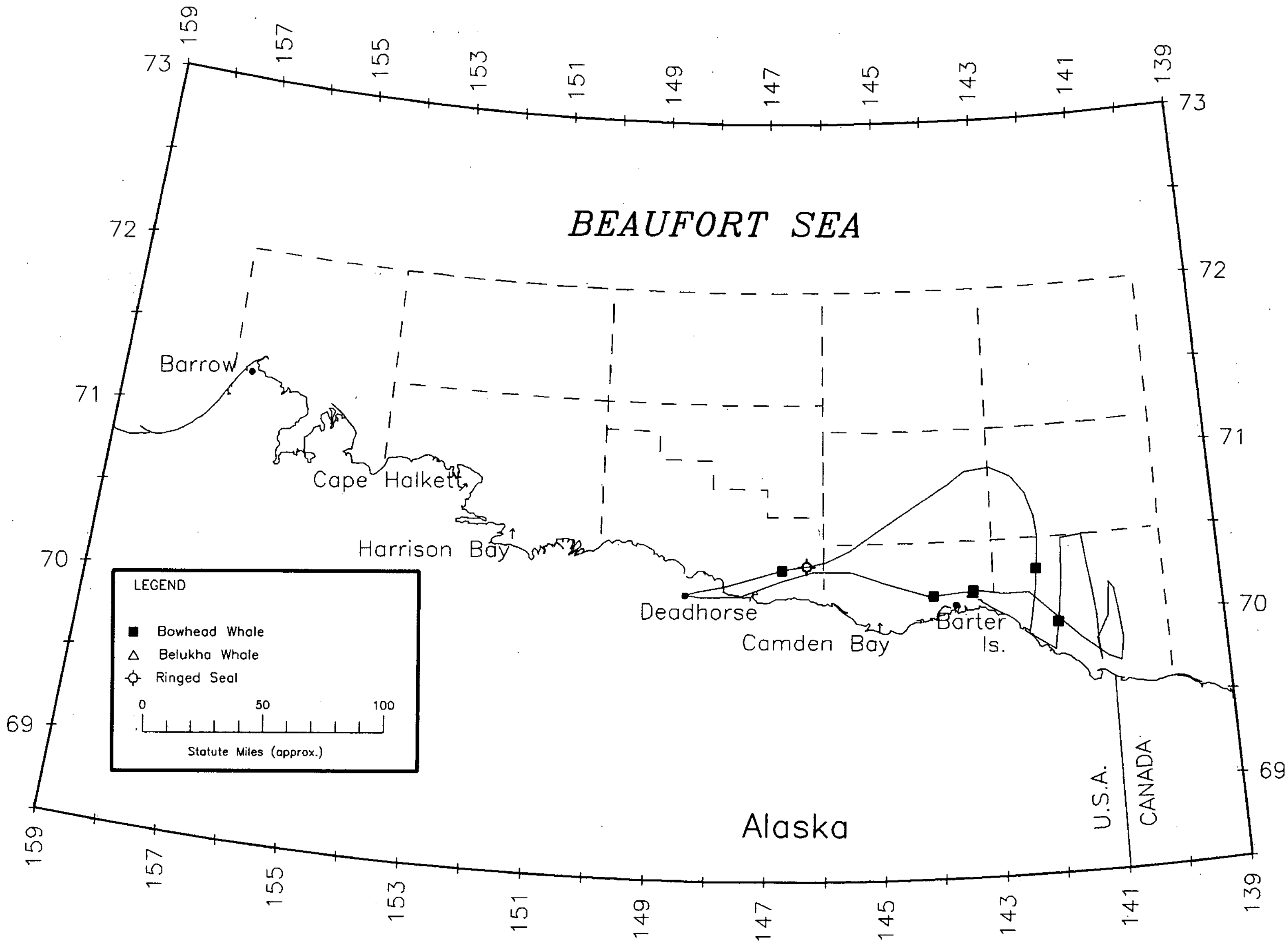
FLIGHT 3 4 September 1993
Survey Track and Sightings



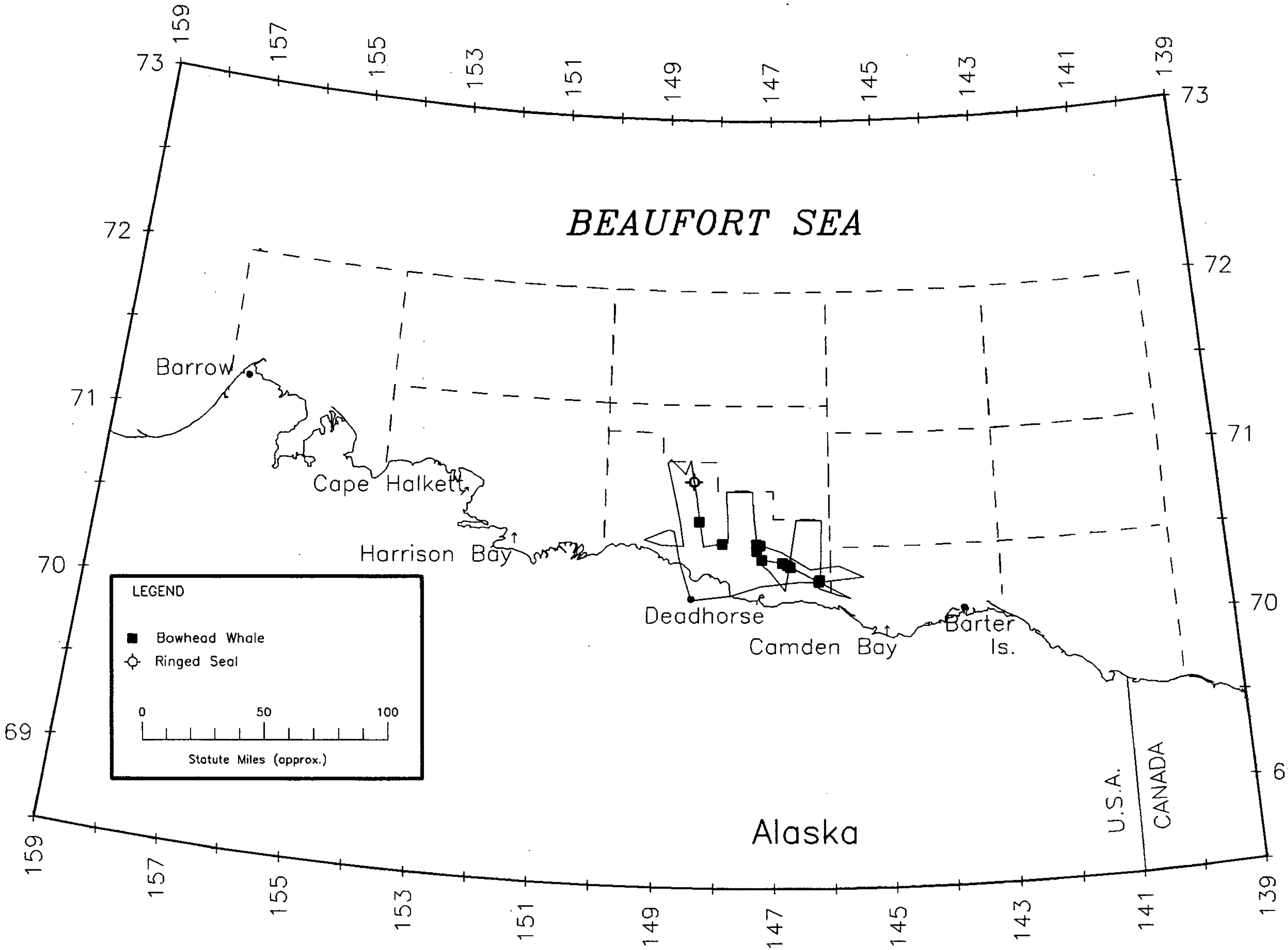
FLIGHT 4 5 September 1993
Survey Track and Sightings



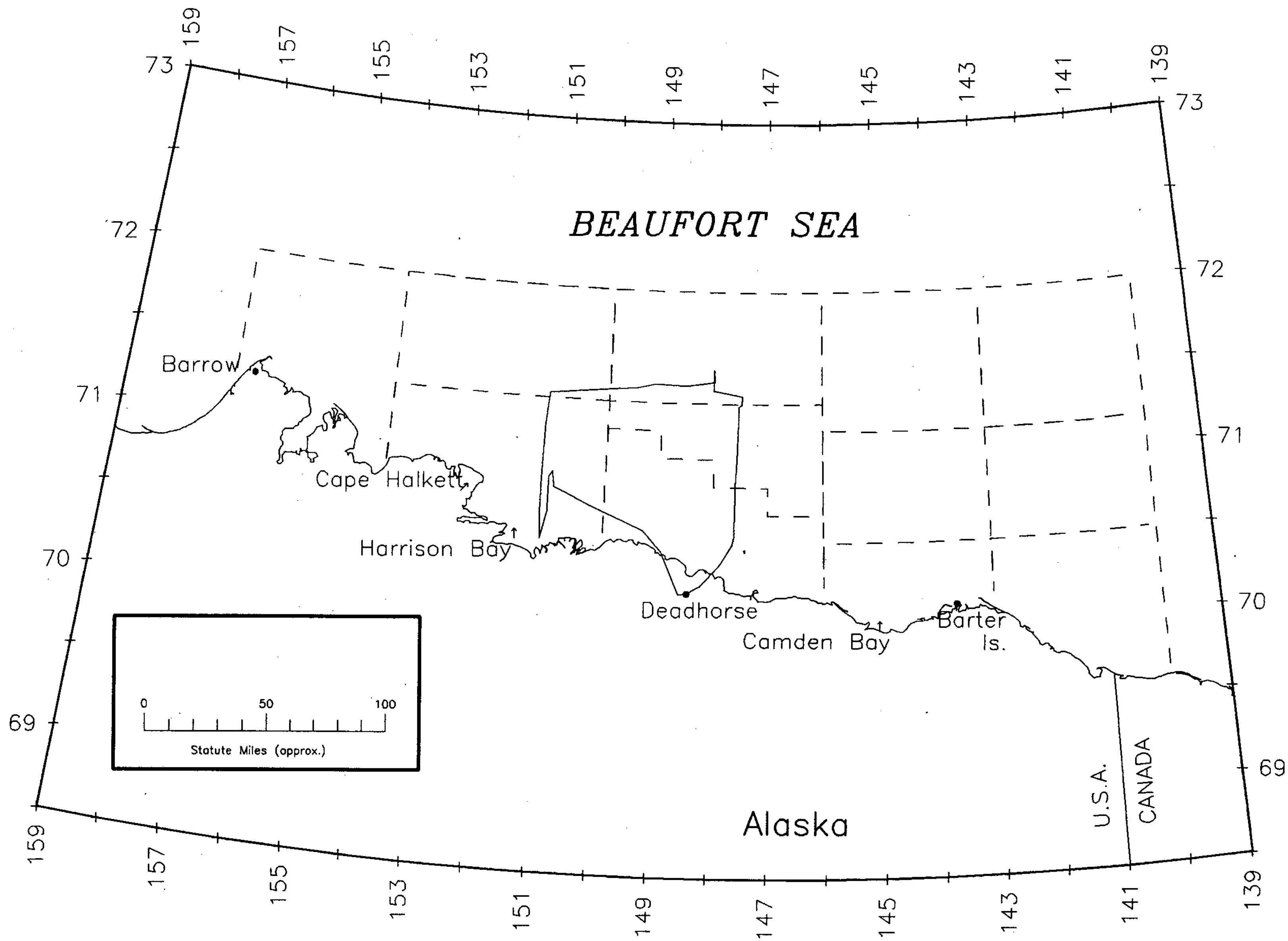
FLIGHT 5 7 September 1993
Survey Track and Sightings



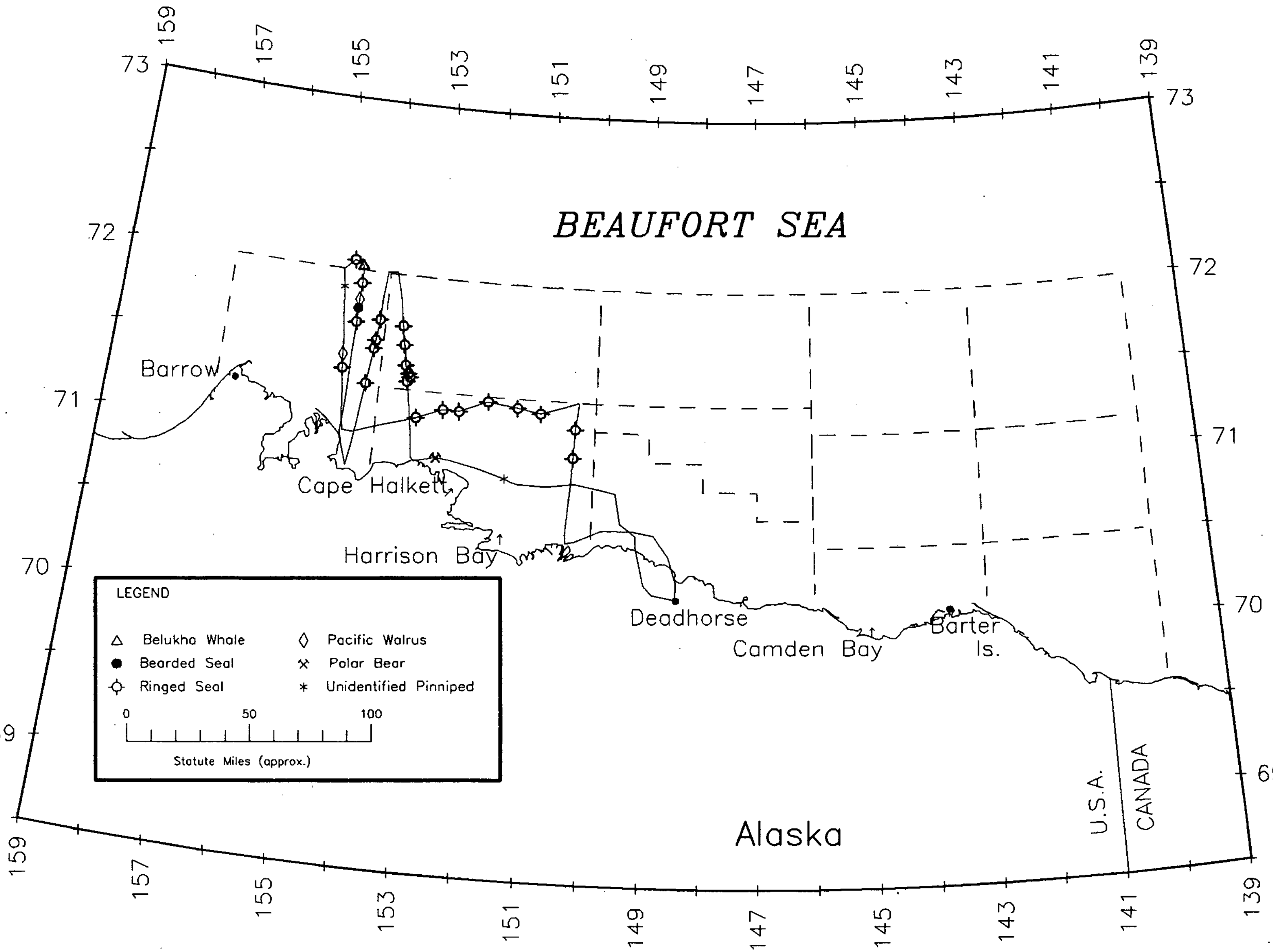
FLIGHT 6 8 September 1993
Survey Track and Sightings



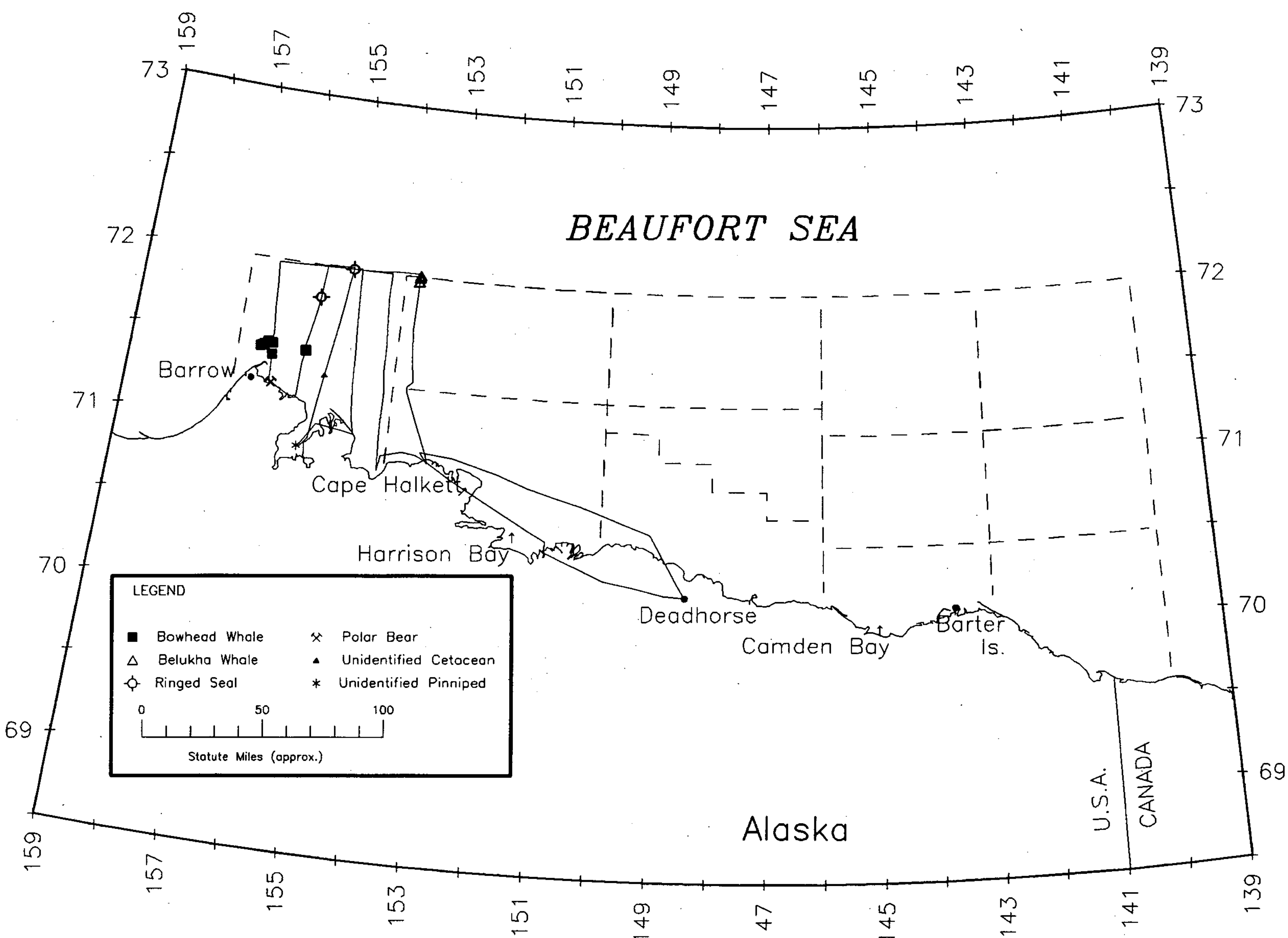
FLIGHT 7 9 September 1993
Survey Track and Sightings



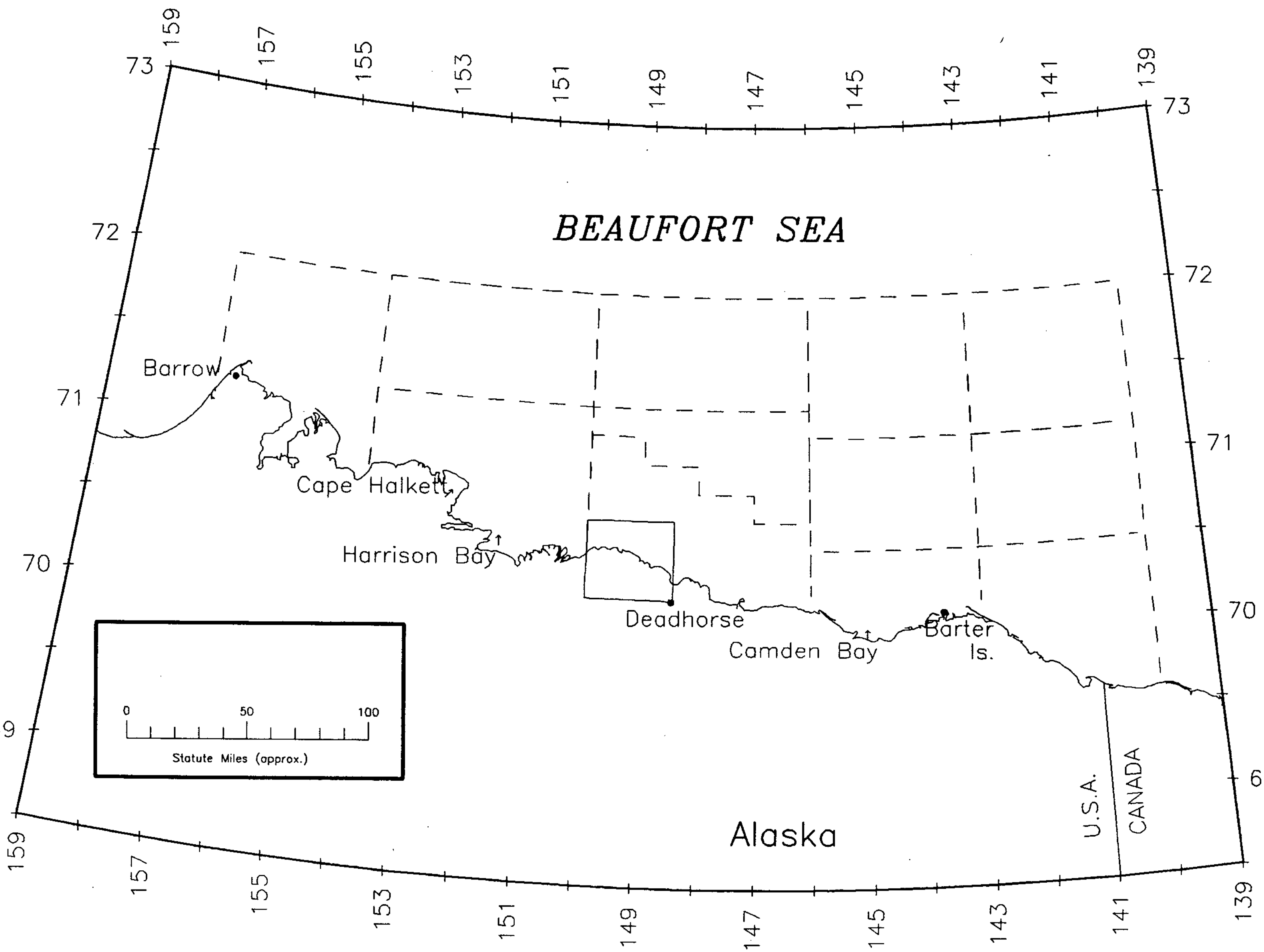
FLIGHT 8 10 September 1993
Survey Track and Sightings



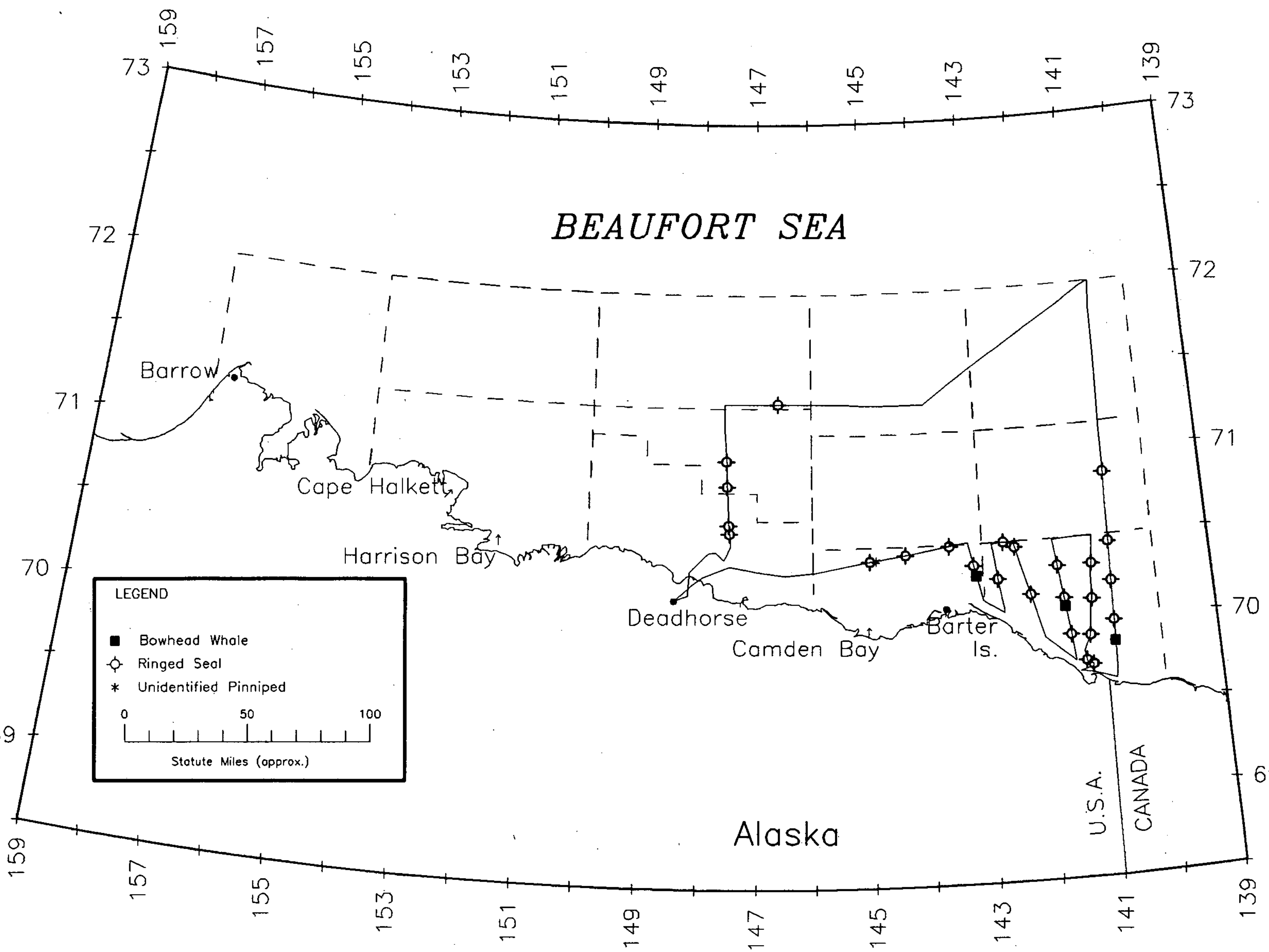
FLIGHT 9 11 September 1993
Survey Track and Sightings



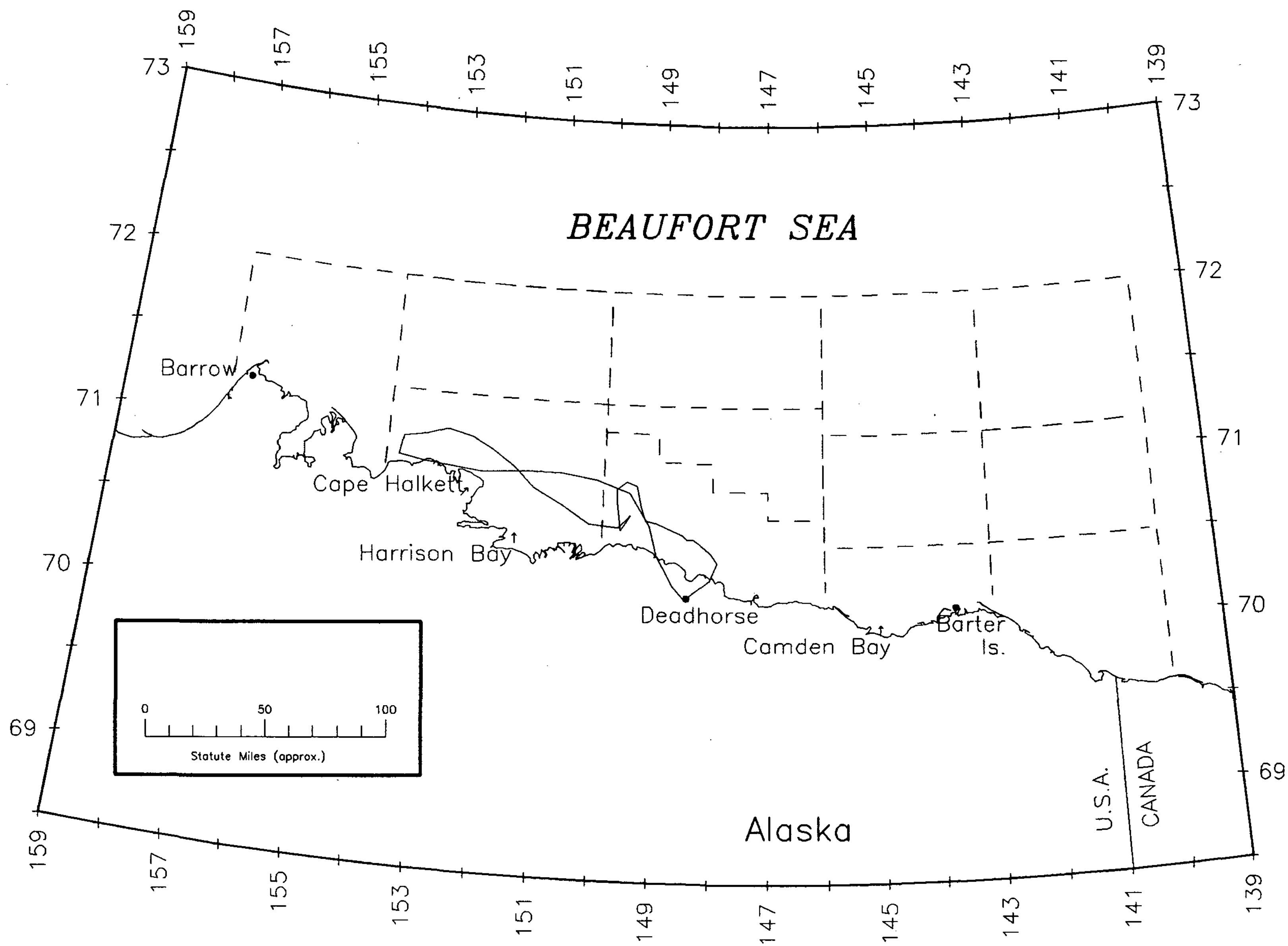
FLIGHT 10 12 September 1993
Survey Track and Sightings



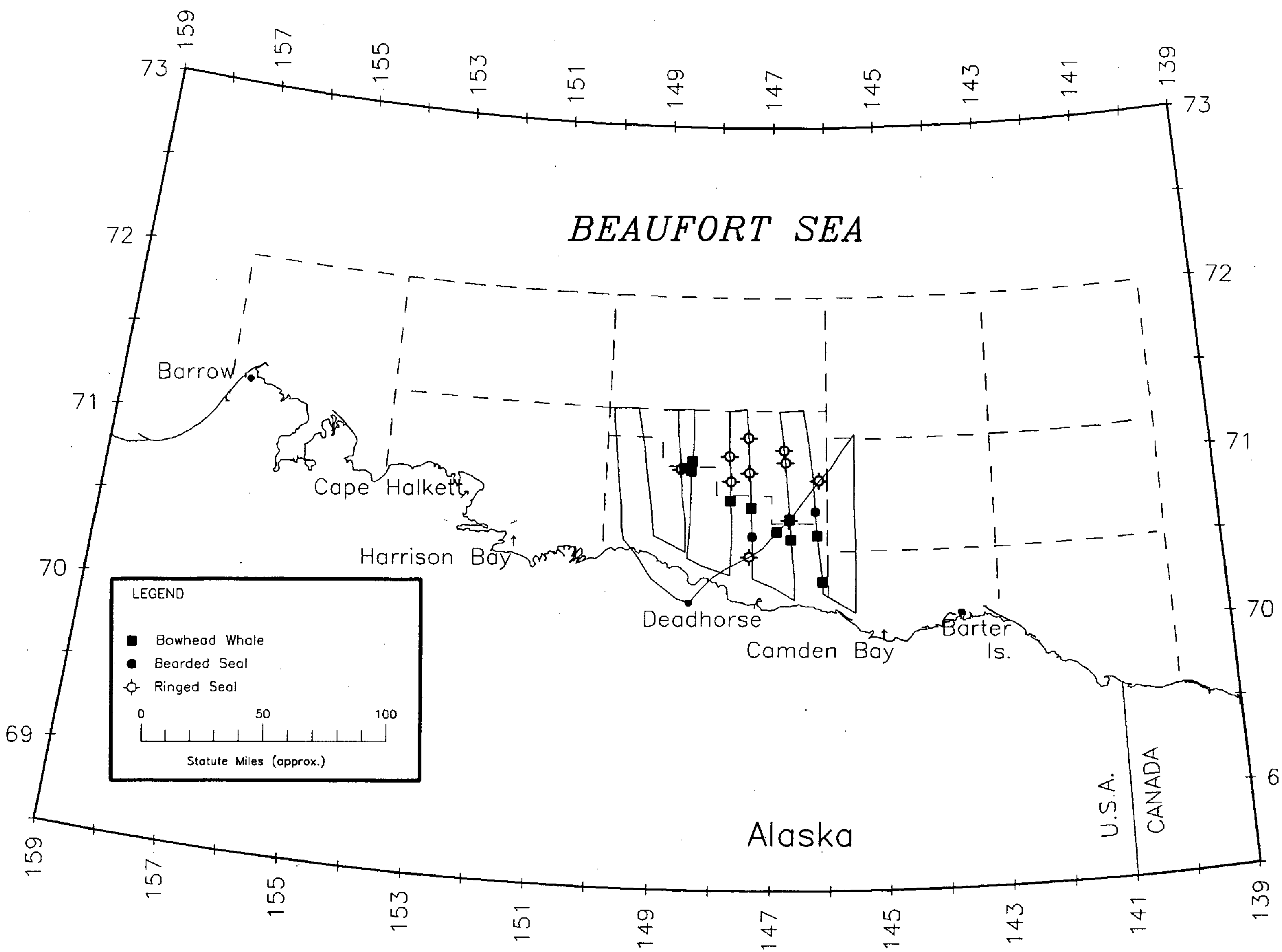
FLIGHT 11 14 September 1993
Survey Track and Sightings



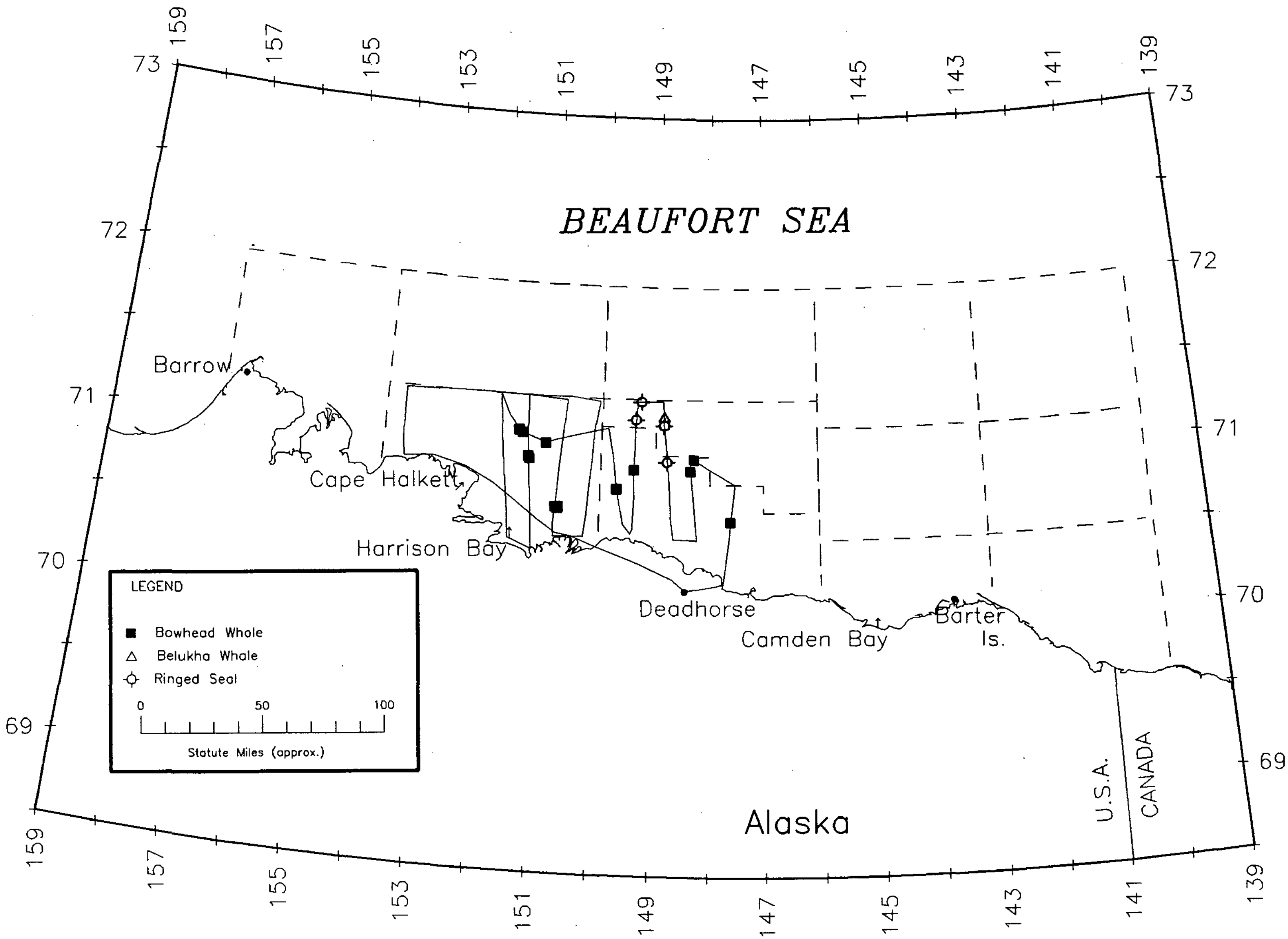
FLIGHT 12 15 September 1993
Survey Track and Sightings



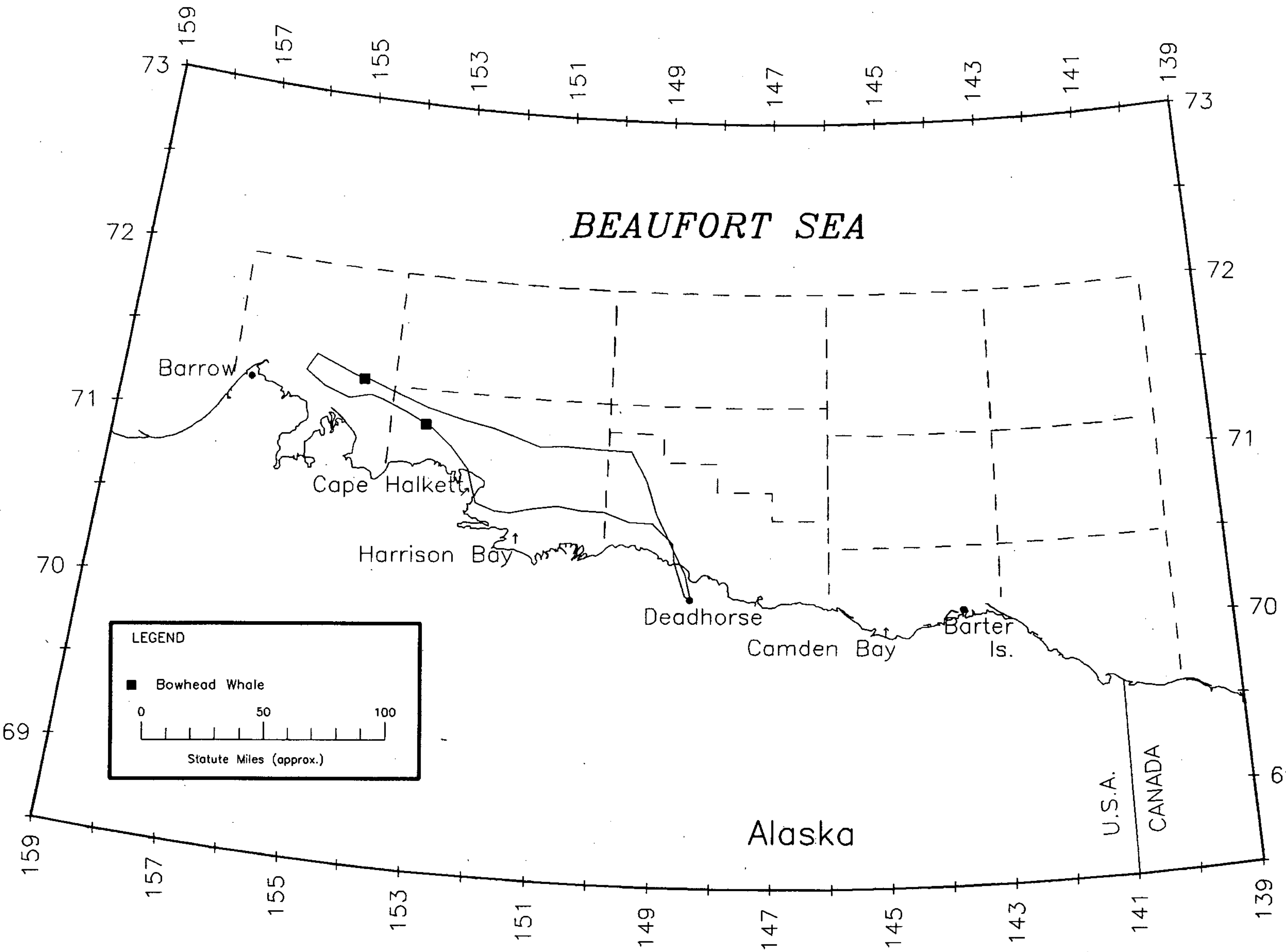
FLIGHT 13 16 September 1993
Survey Track and Sightings



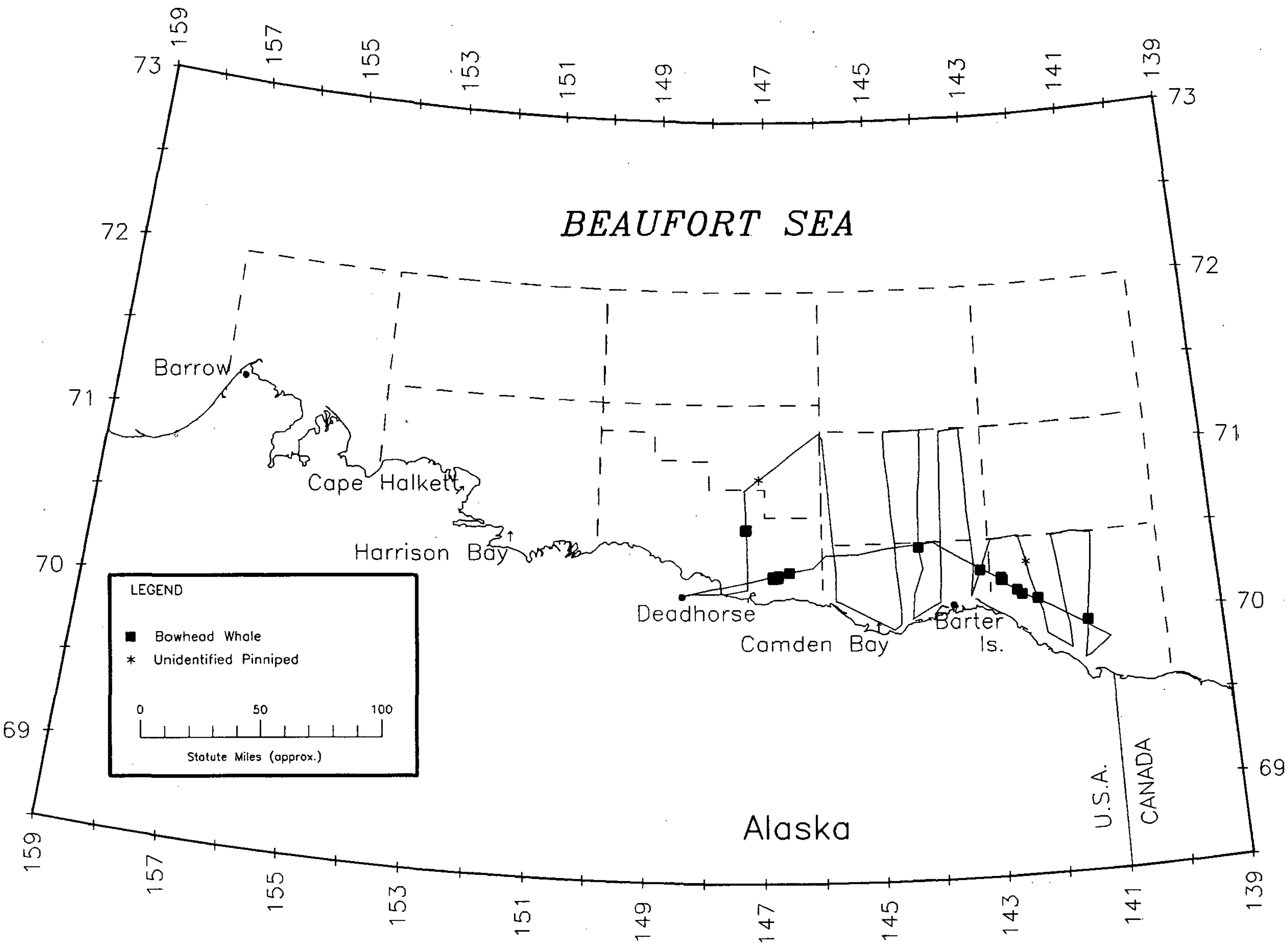
FLIGHT 14 19 September 1993
Survey Track and Sightings



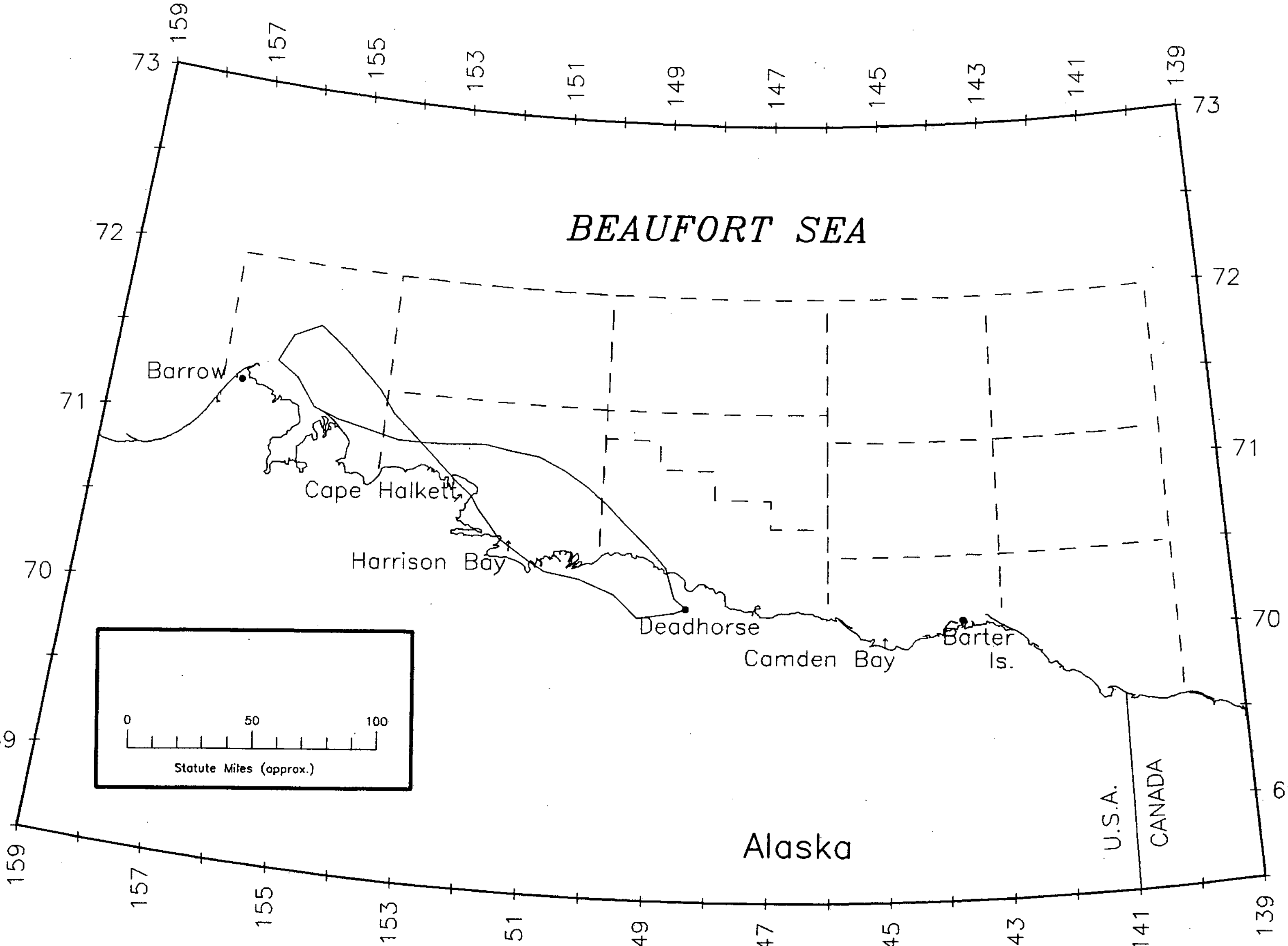
FLIGHT 15 20 September 1993
Survey Track and Sightings



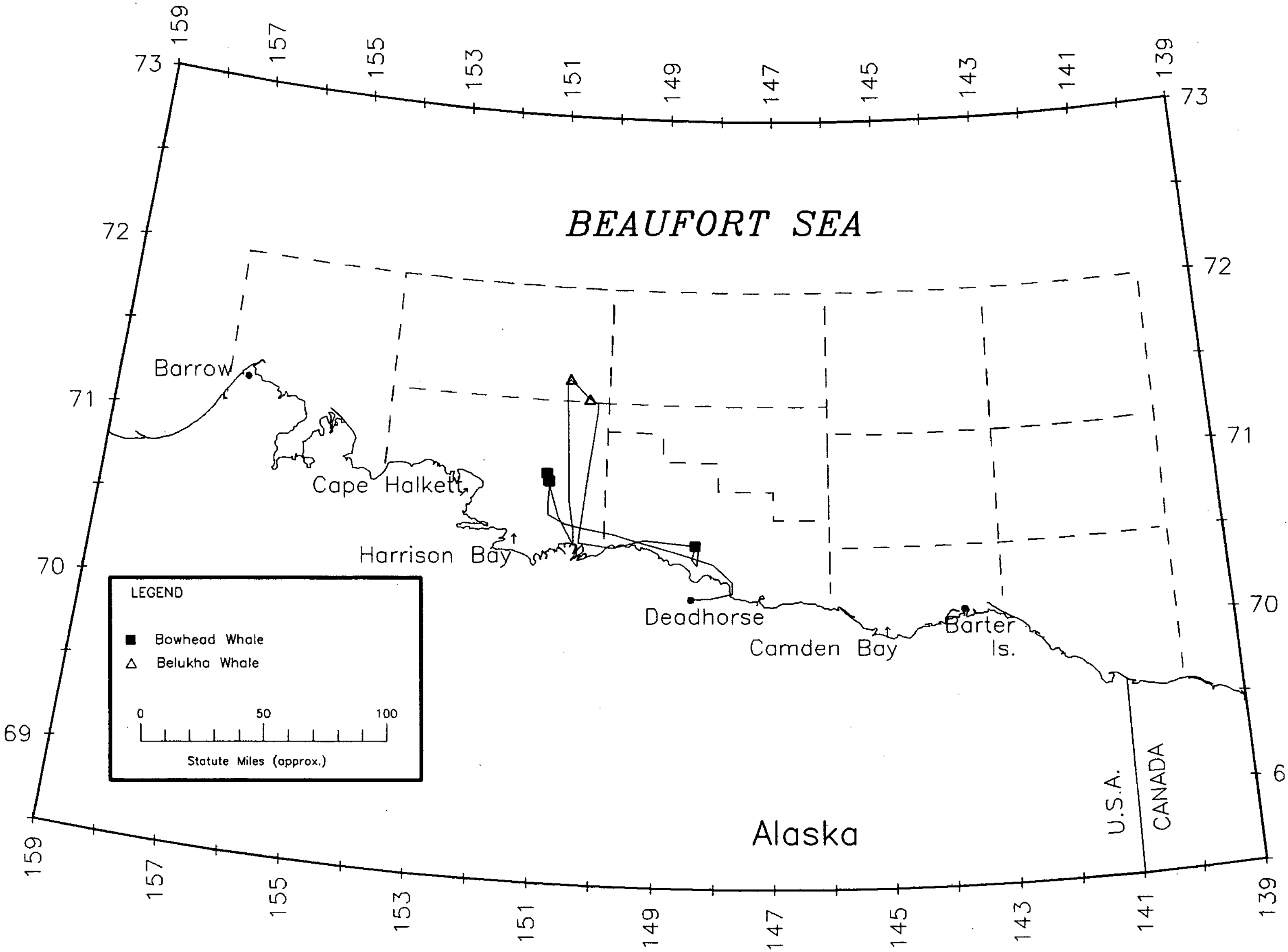
FLIGHT 16 22 September 1993
Survey Track and Sightings



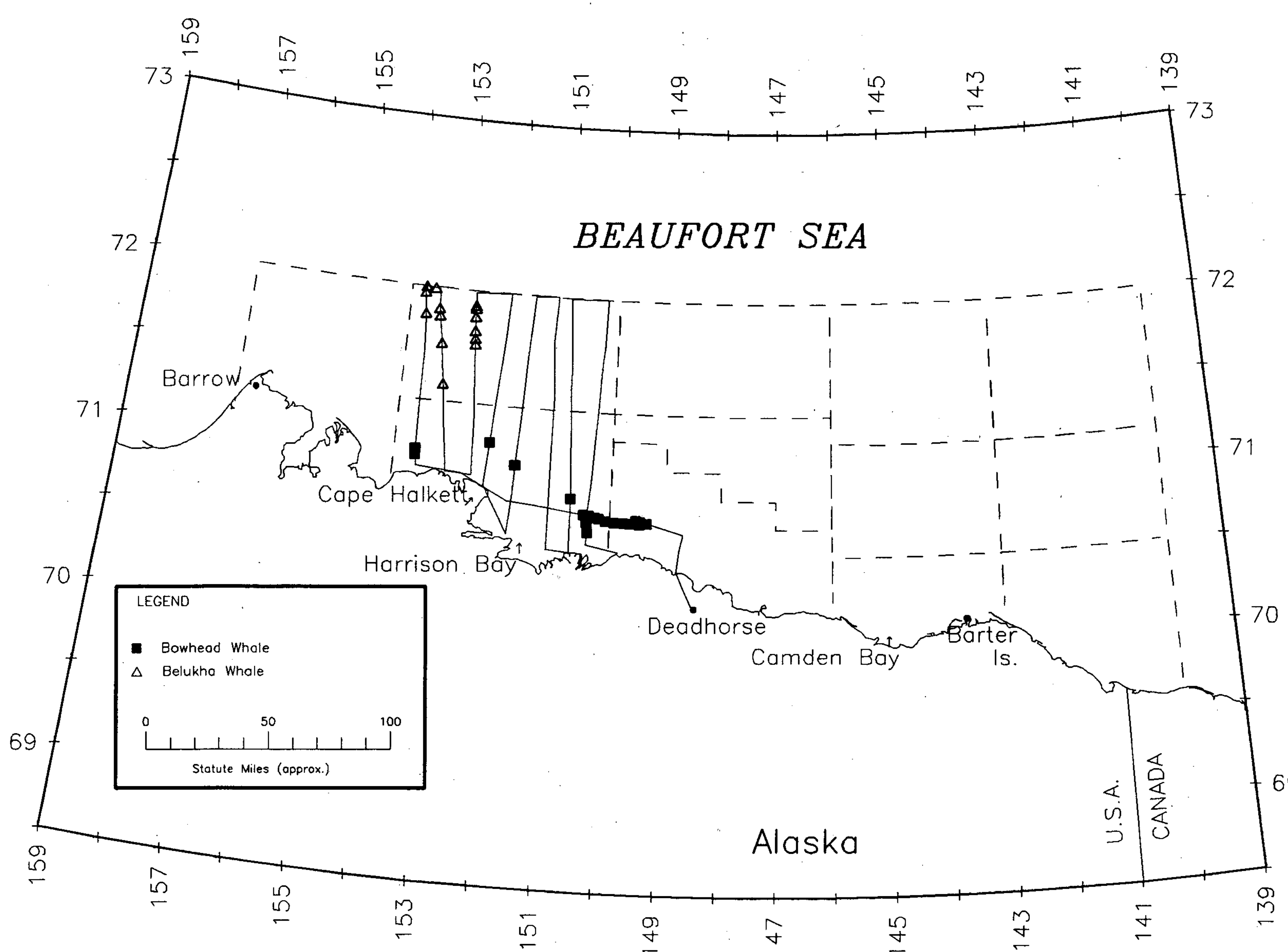
FLIGHT 17 24 September 1993
Survey Track and Sightings



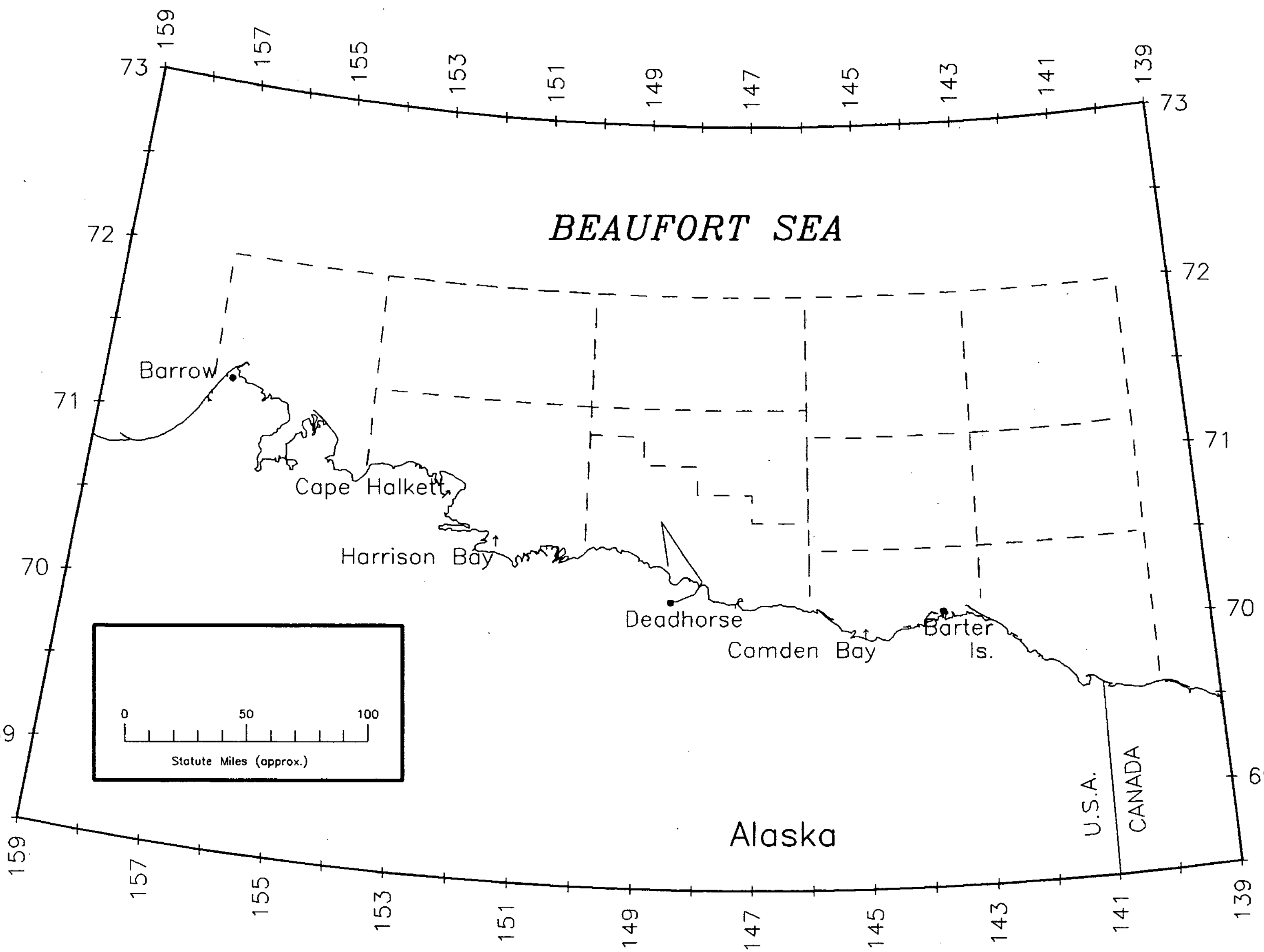
FLIGHT 18 25 September 1993
Survey Track and Sightings



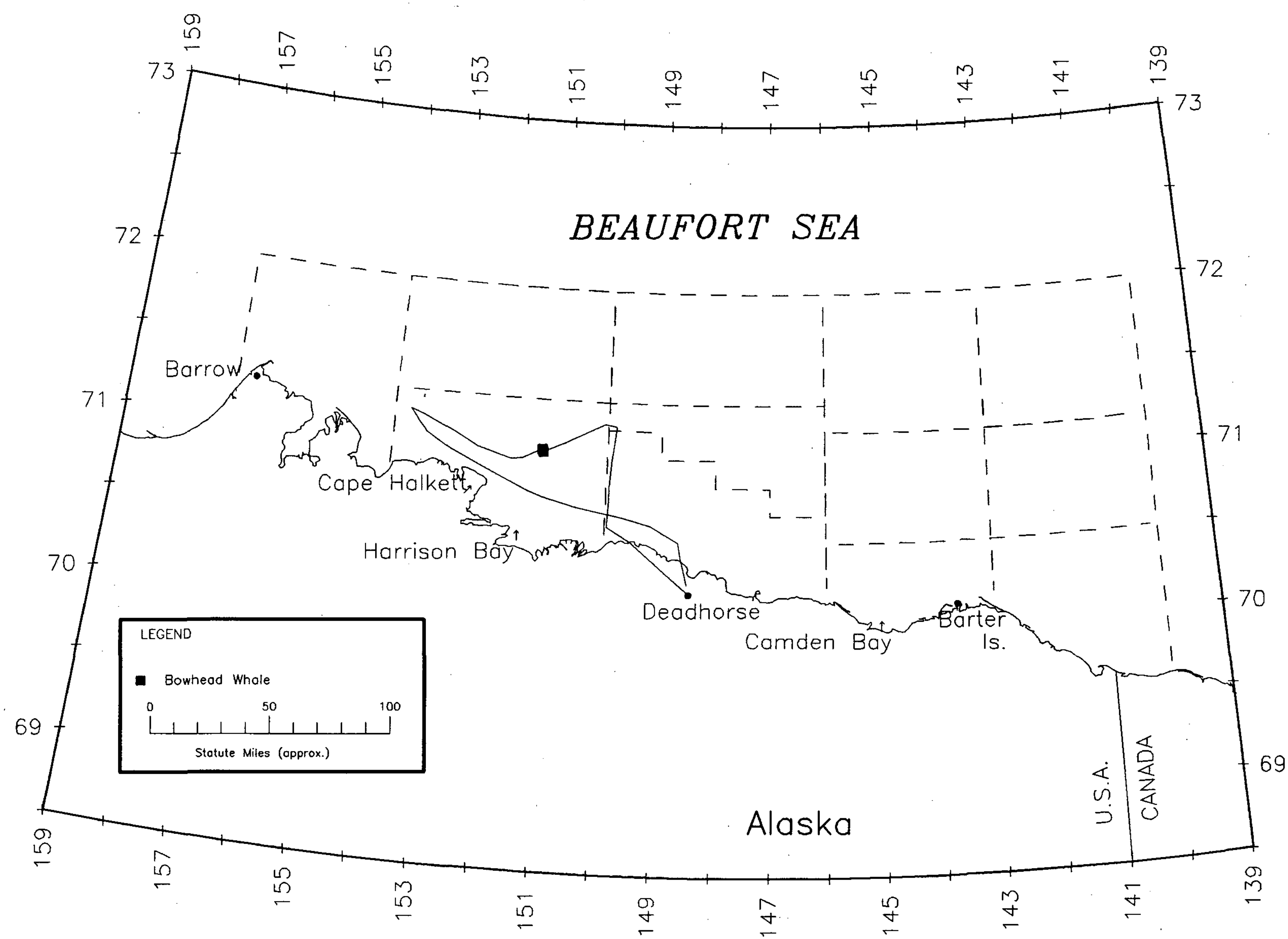
FLIGHT 19 28 September 1993
Survey Track and Sightings



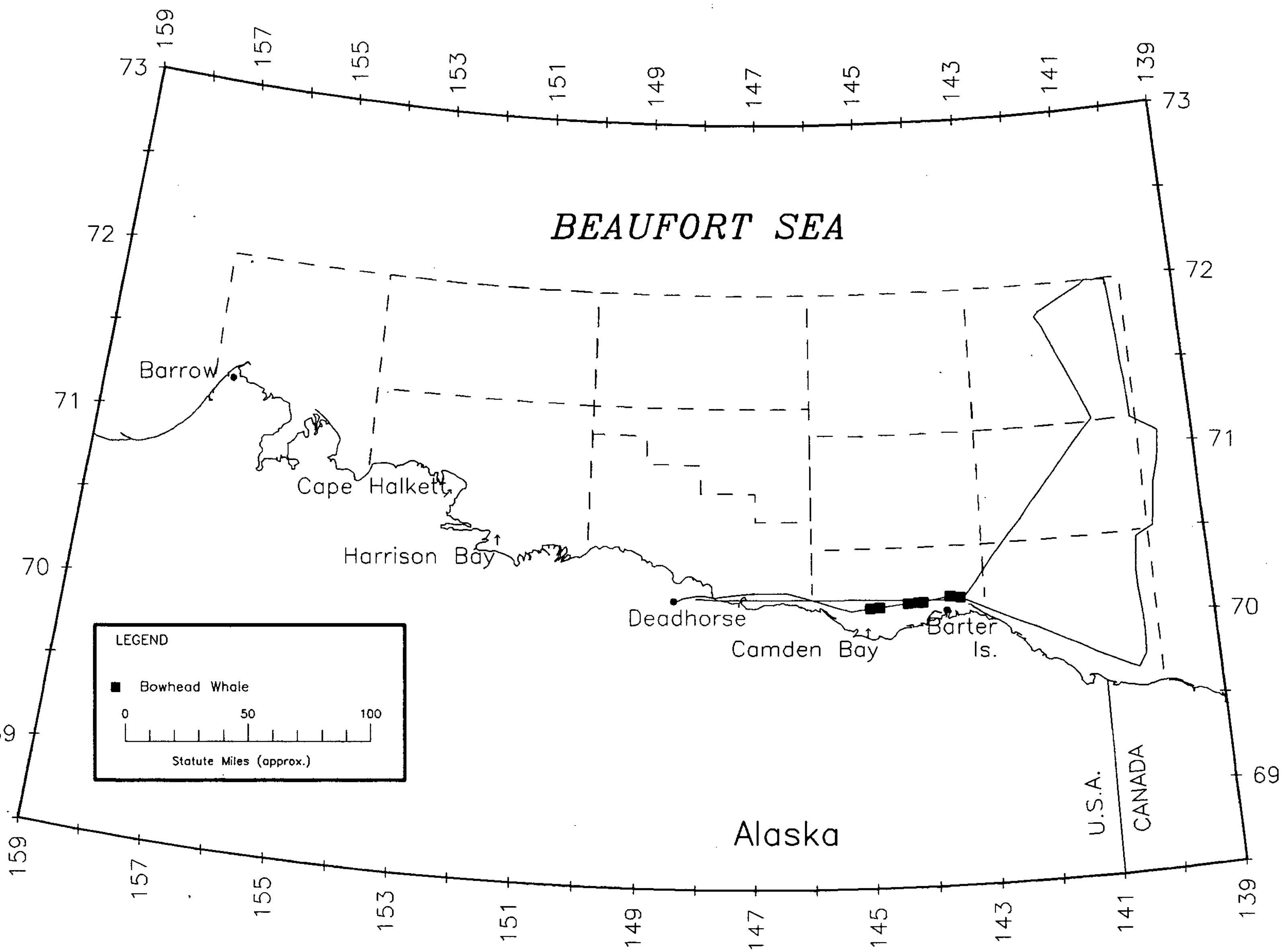
FLIGHT 20 29 September 1993
Survey Track and Sightings



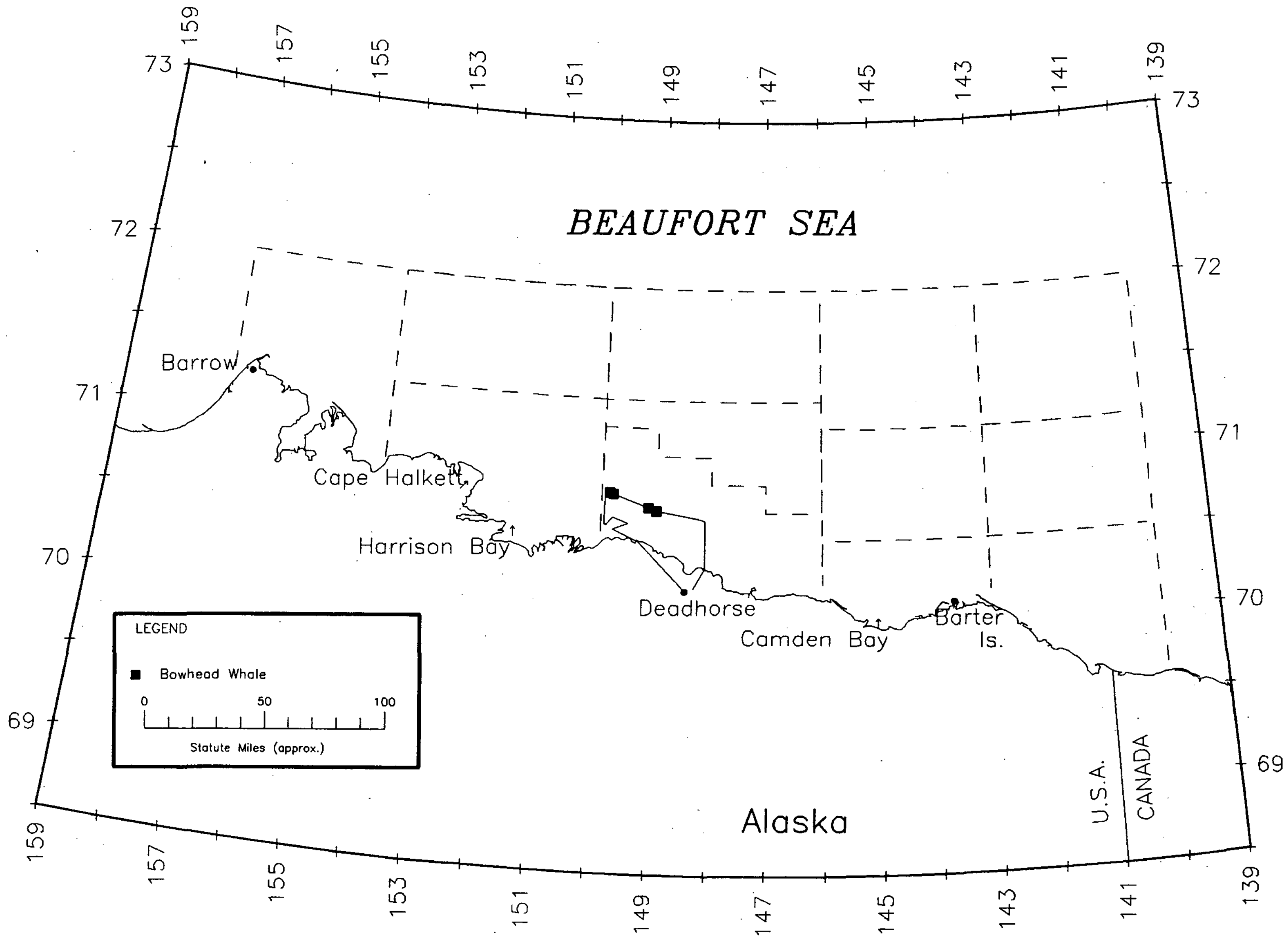
FLIGHT 21 30 September 1993
Survey Track and Sightings



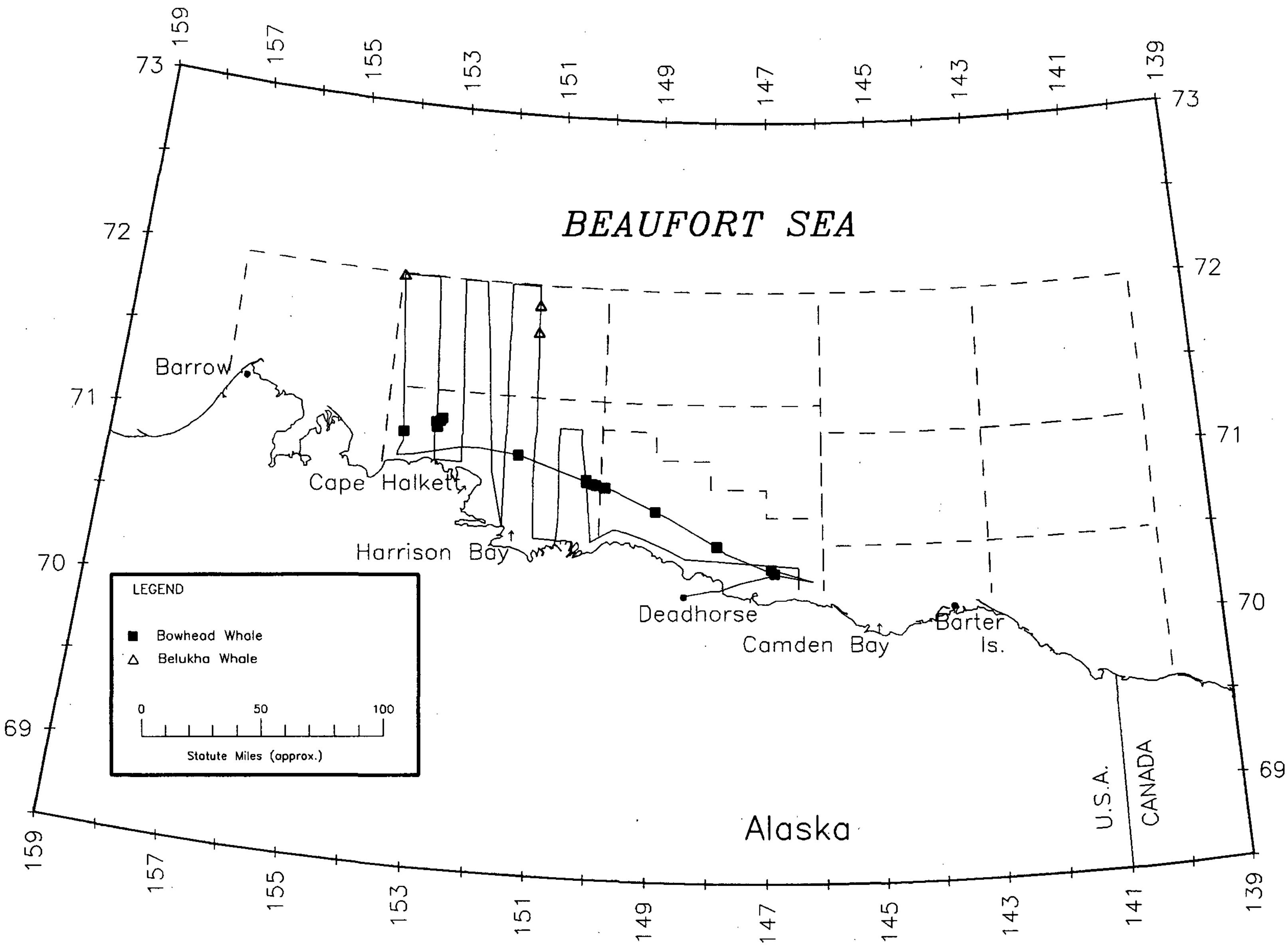
FLIGHT 22 2 October 1993
Survey Track and Sightings



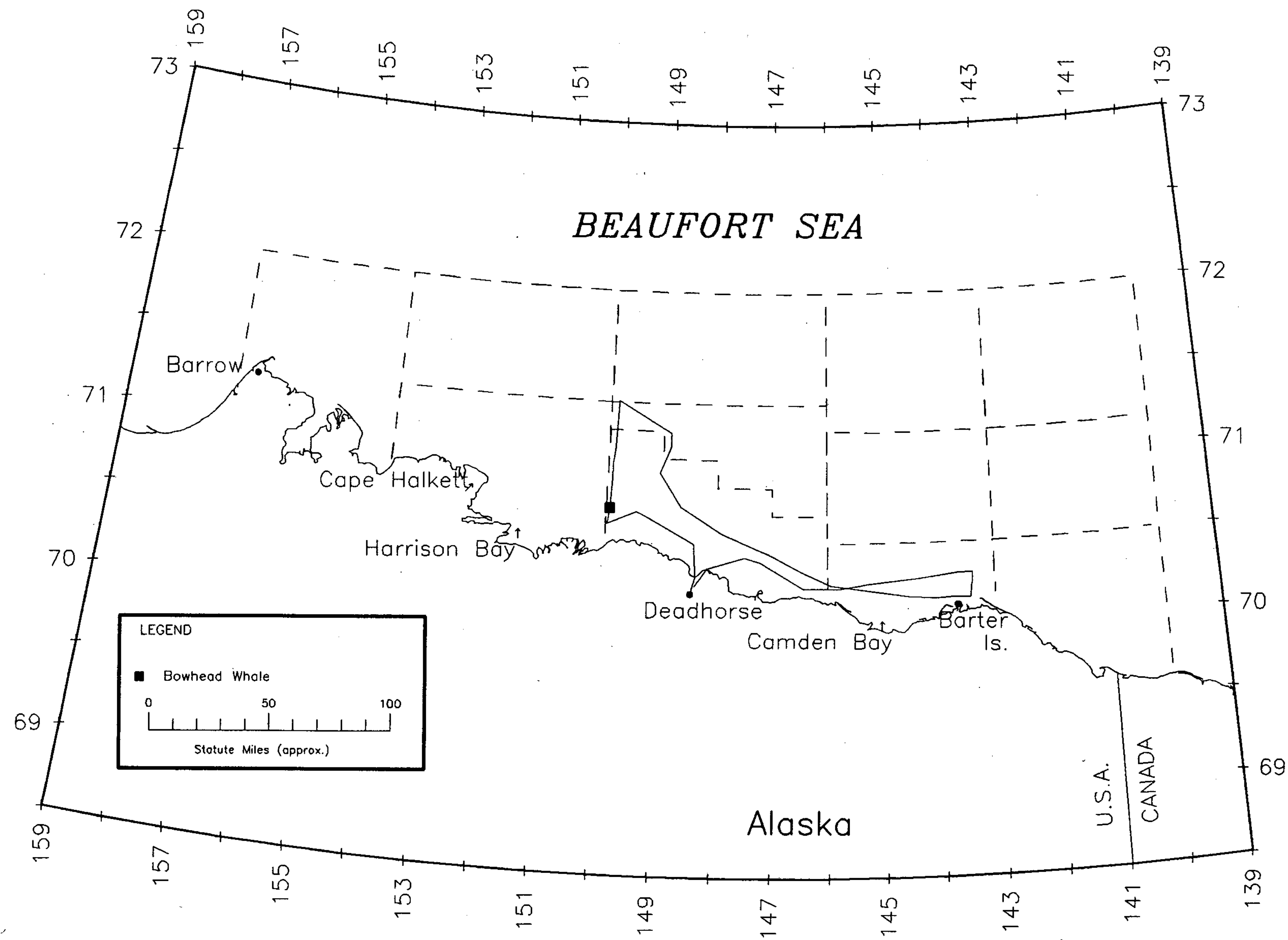
FLIGHT 23 3 October 1993
Survey Track and Sightings



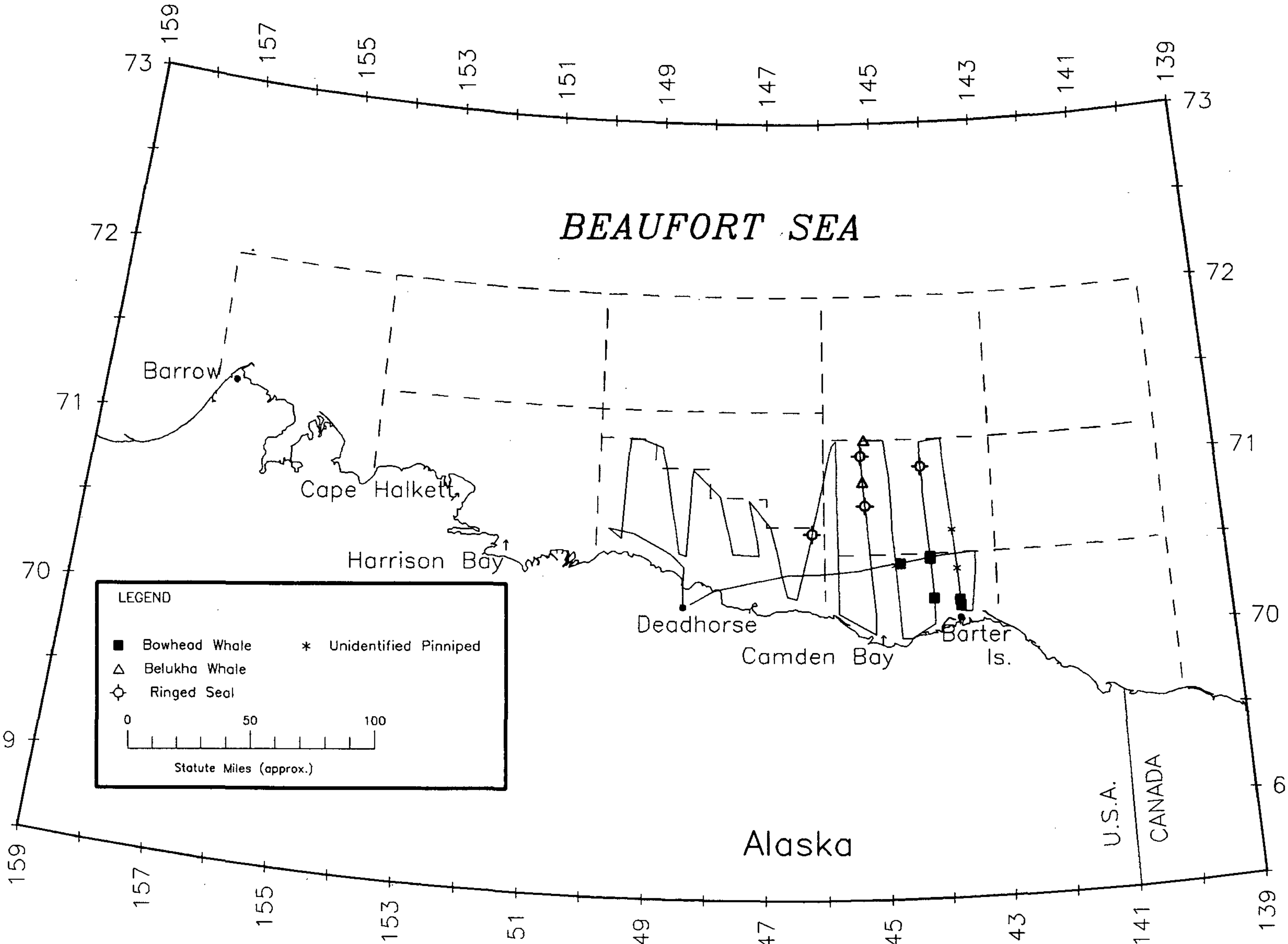
FLIGHT 24 4 October 1993
Survey Track and Sightings



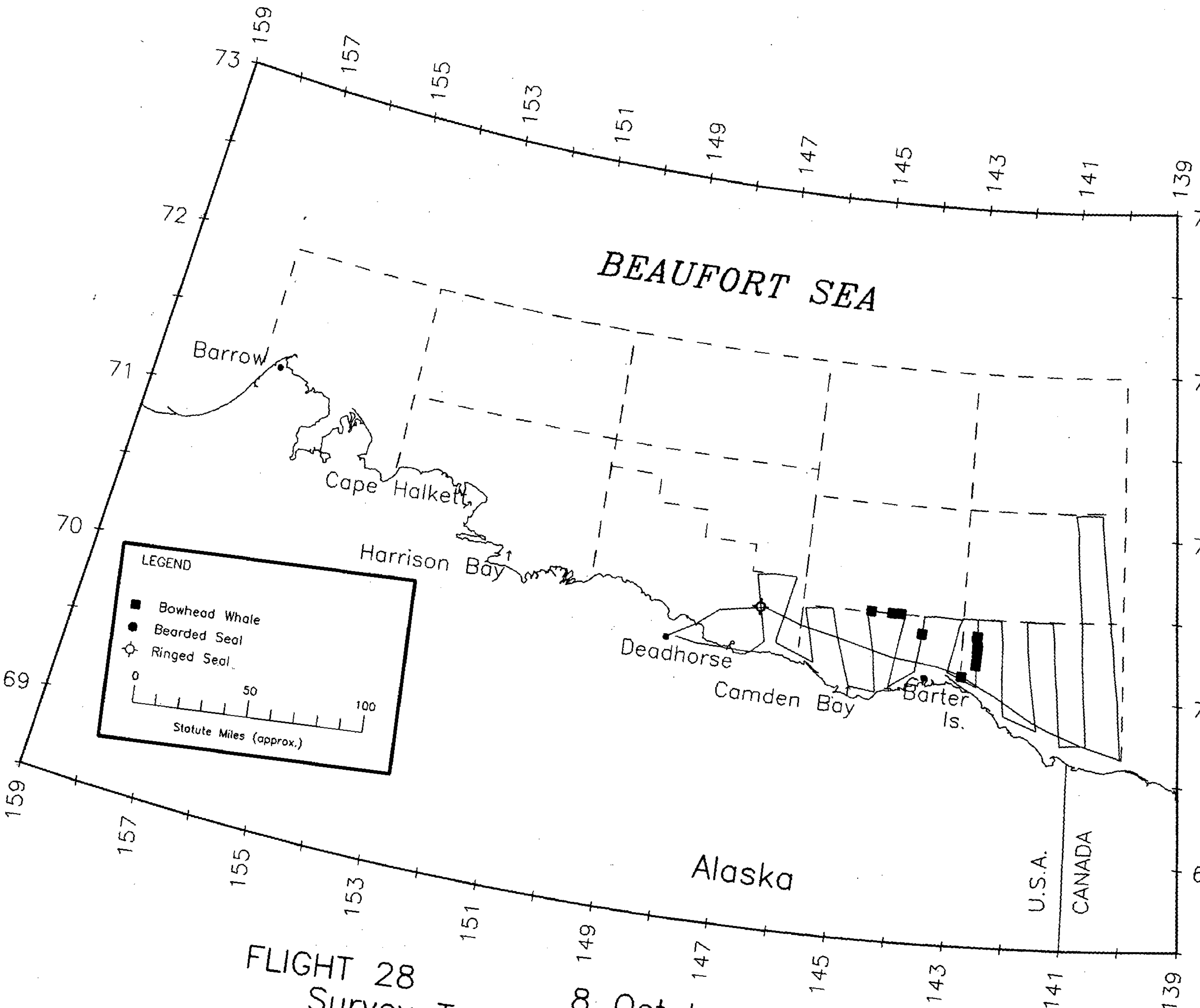
FLIGHT 25 5 October 1993
Survey Track and Sightings



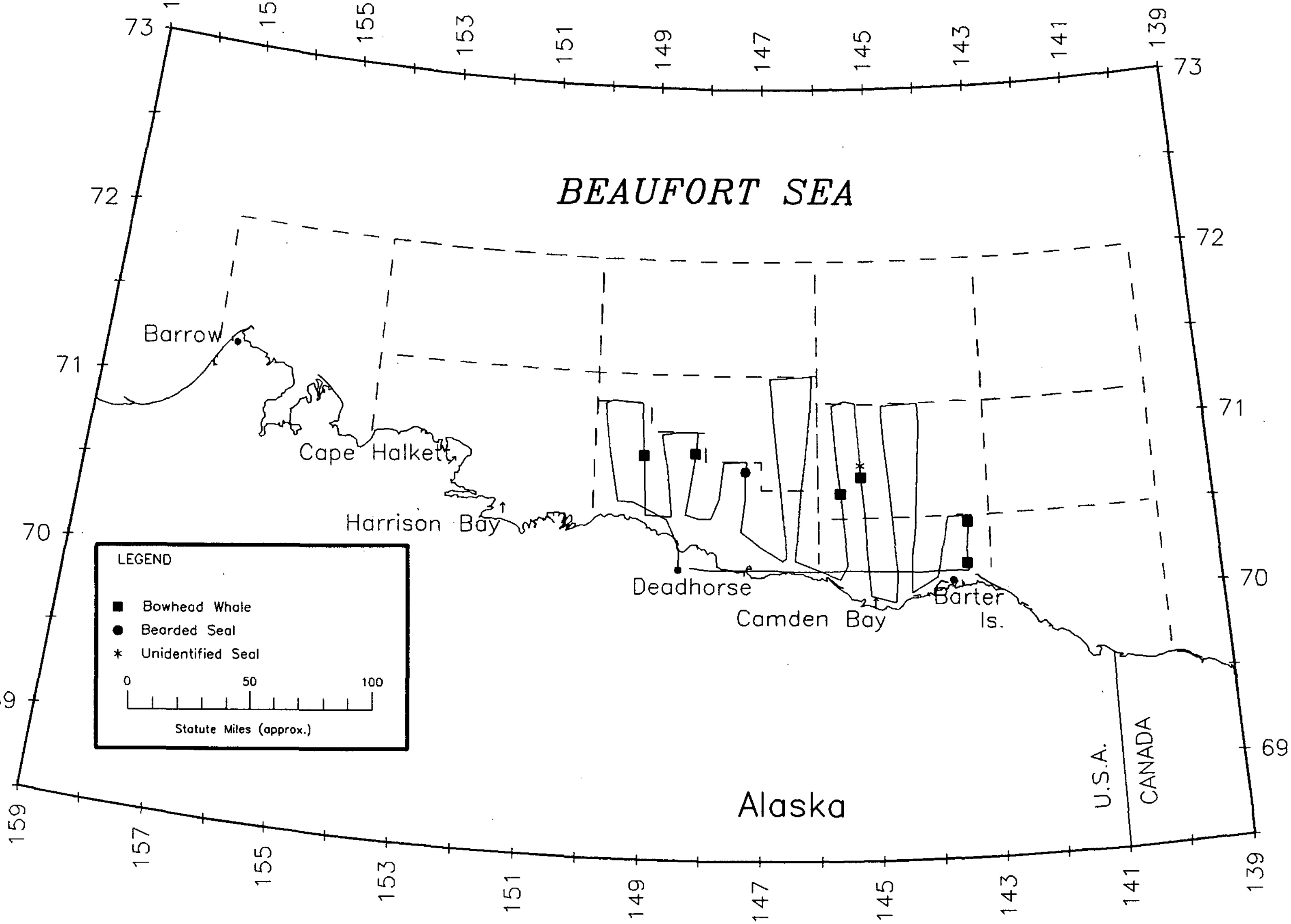
FLIGHT 26 6 October 1993
Survey Track and Sightings



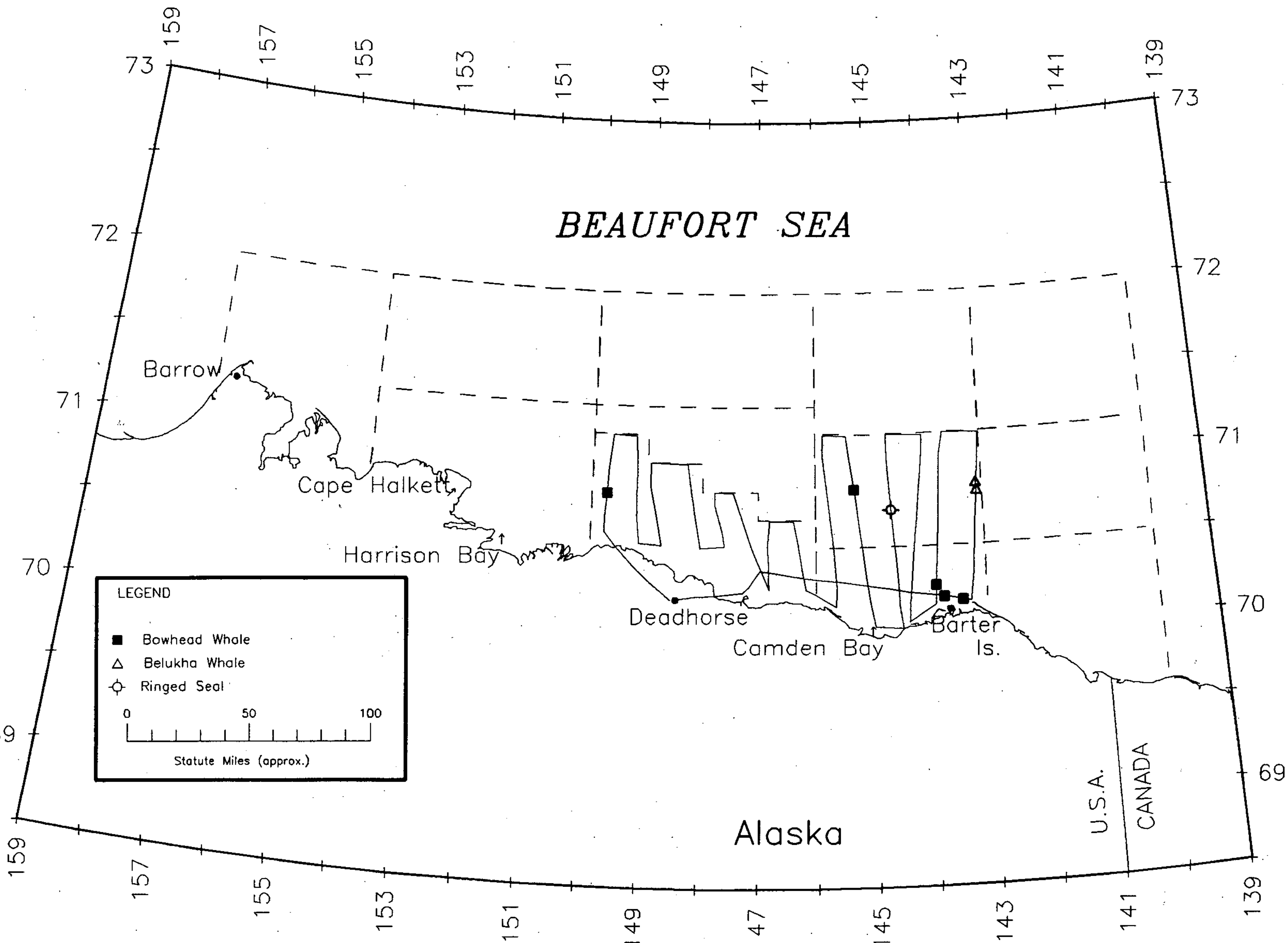
FLIGHT 27 7 October 1993
Survey Track and Sightings



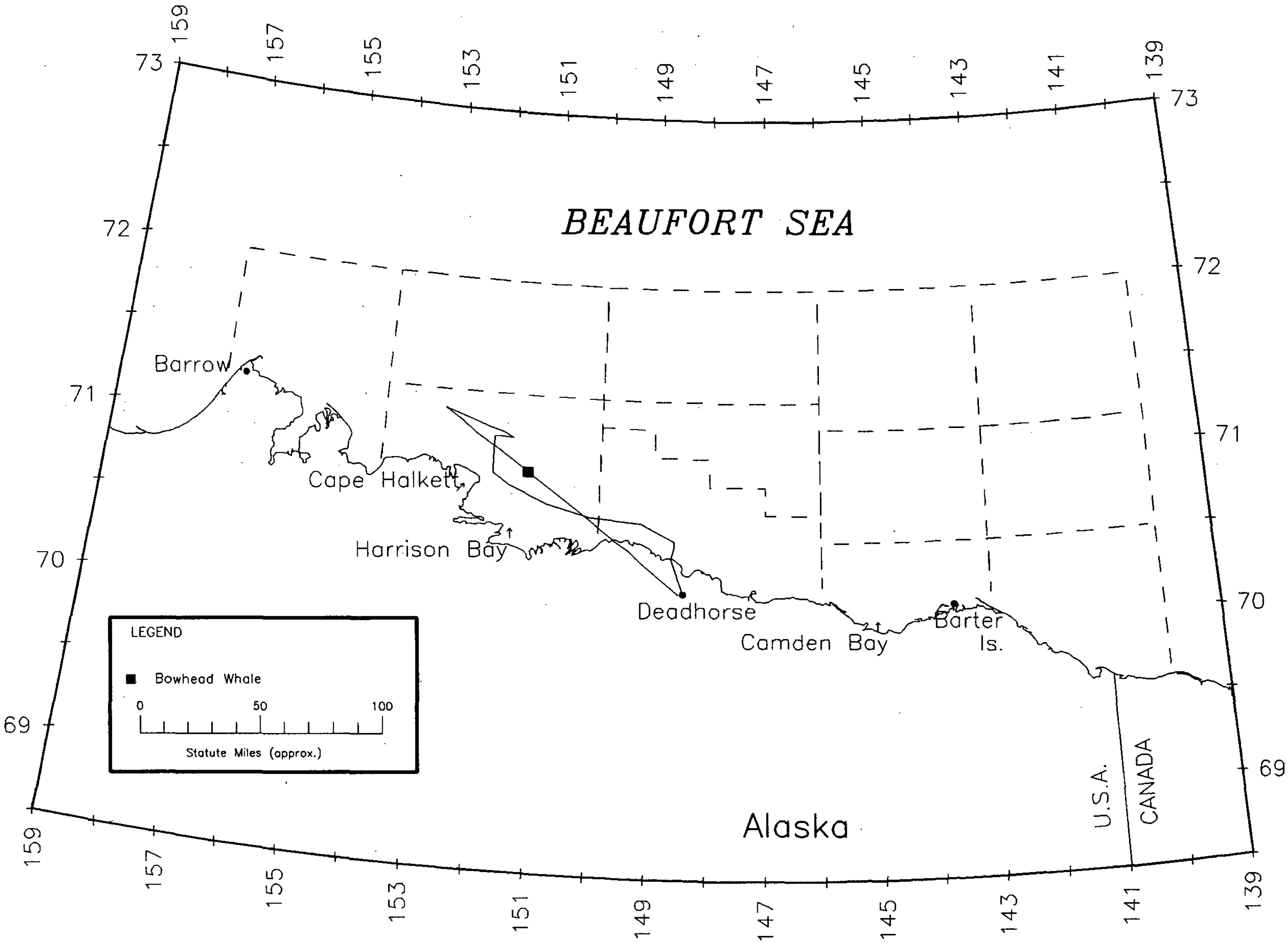
FLIGHT 28 8 October 1993
Survey Track and Sightings



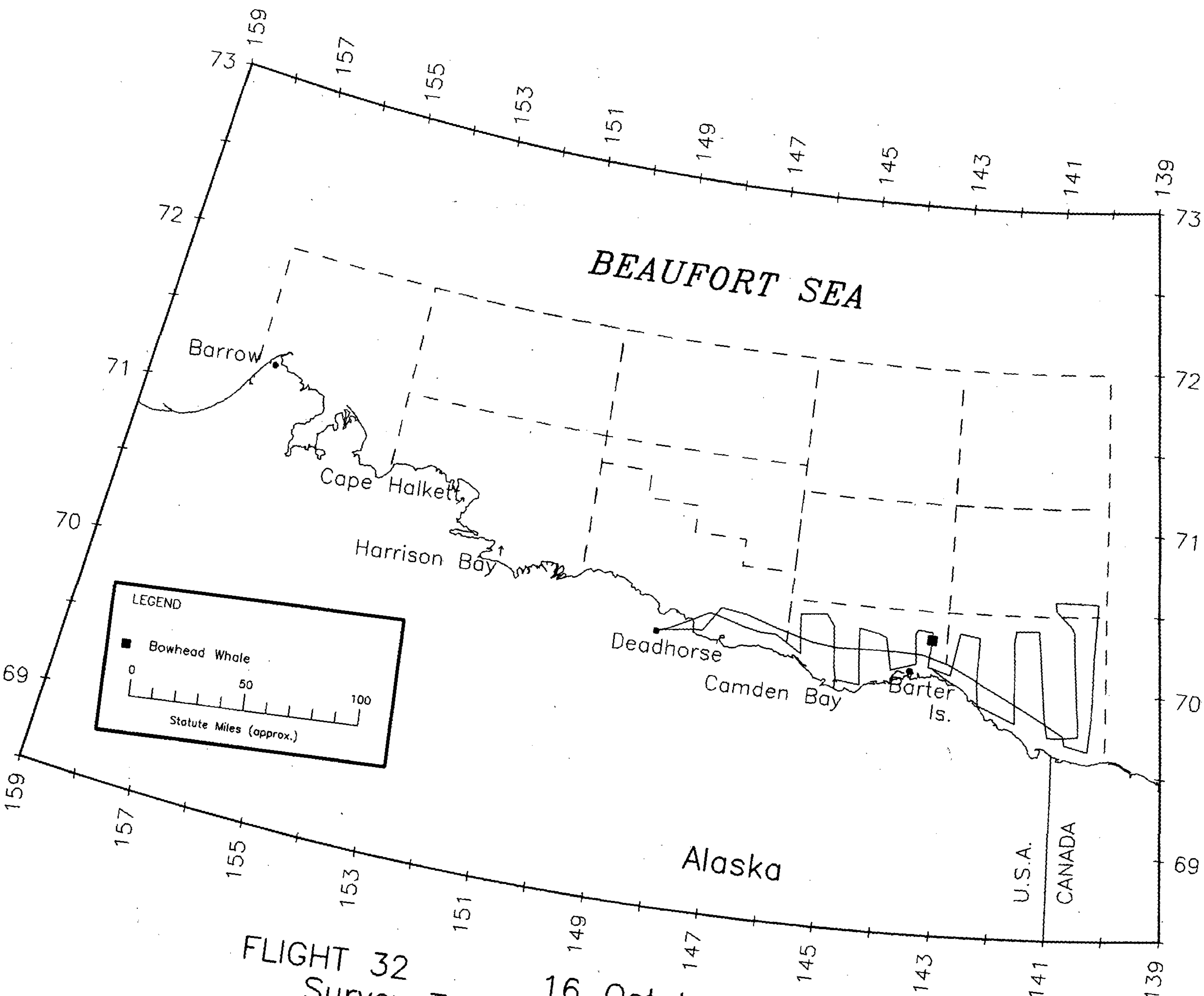
FLIGHT 29 10 October 1993
Survey Track and Sightings



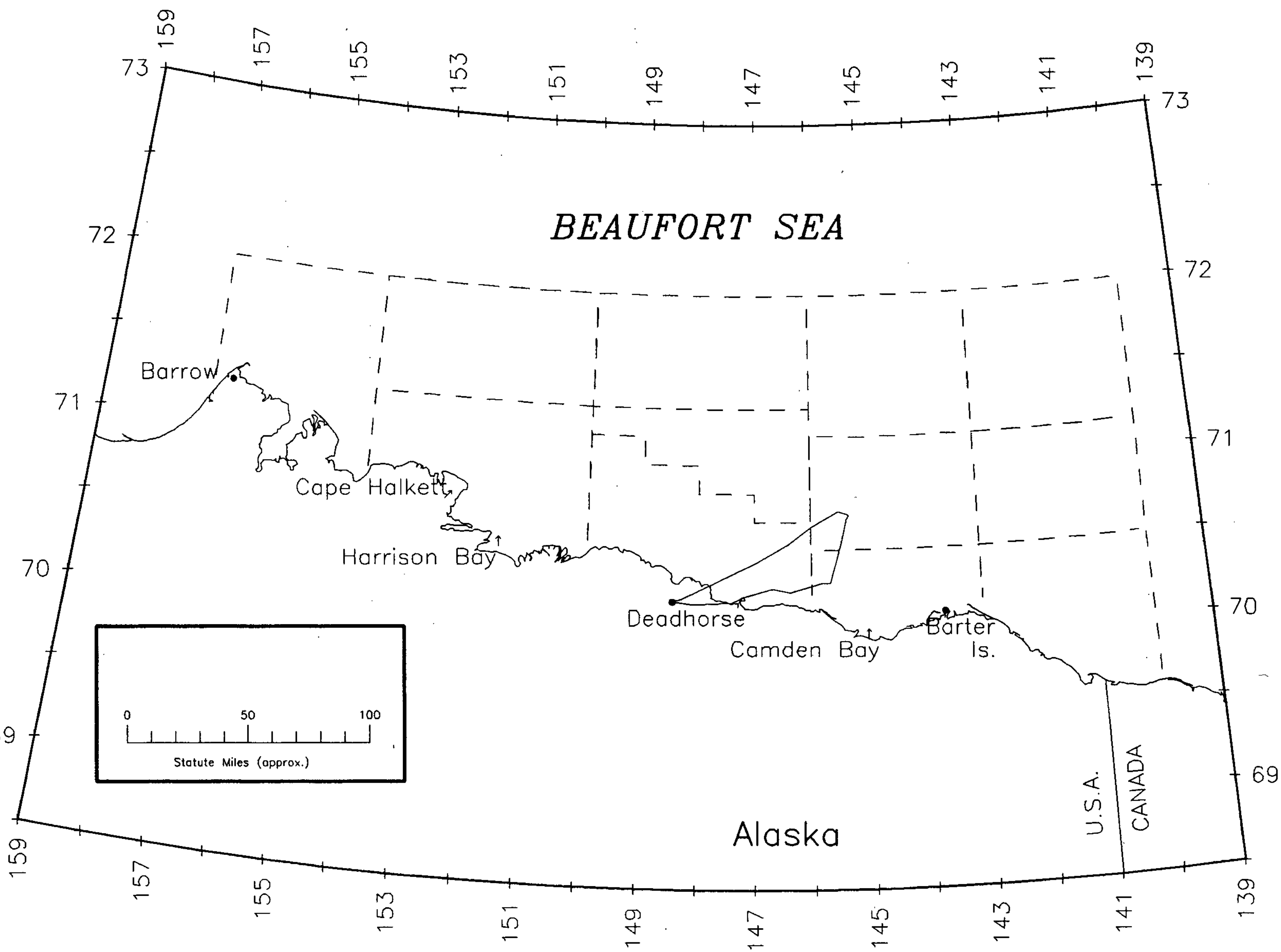
FLIGHT 30 13 October 1993
Survey Track and Sightings



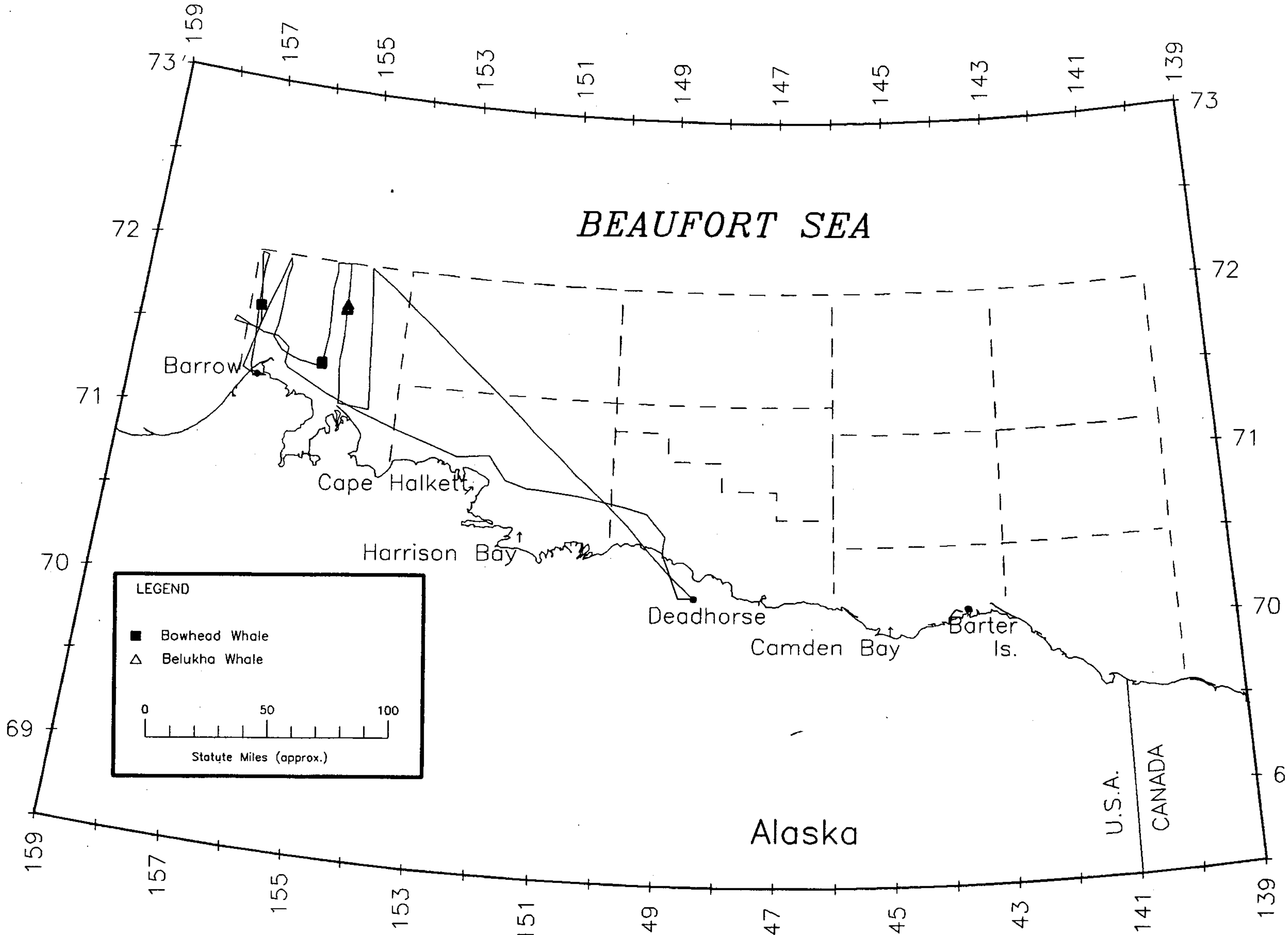
FLIGHT 31 14 October 1993
Survey Track and Sightings



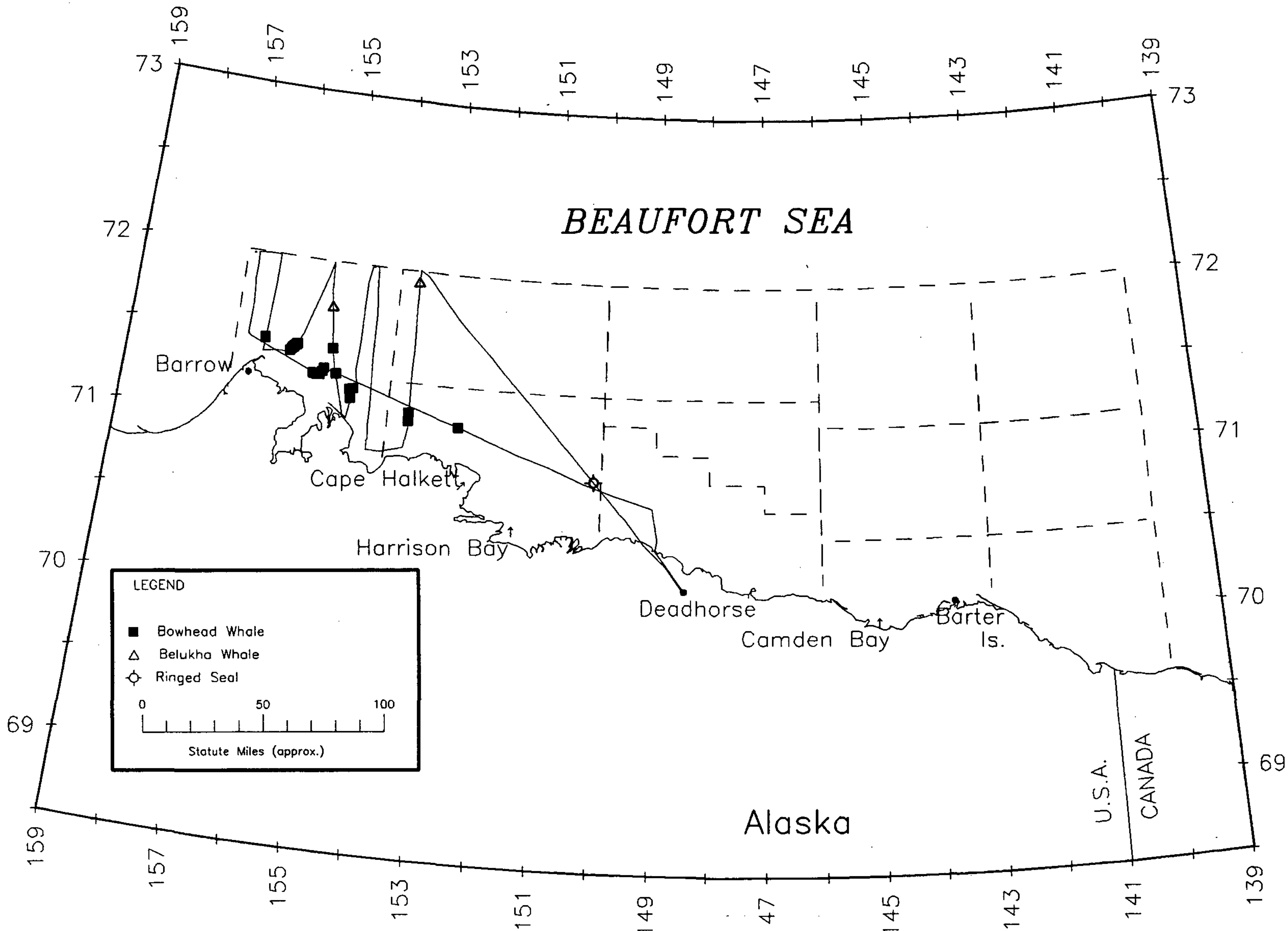
FLIGHT 32 16 October 1993
Survey Track and Sightings



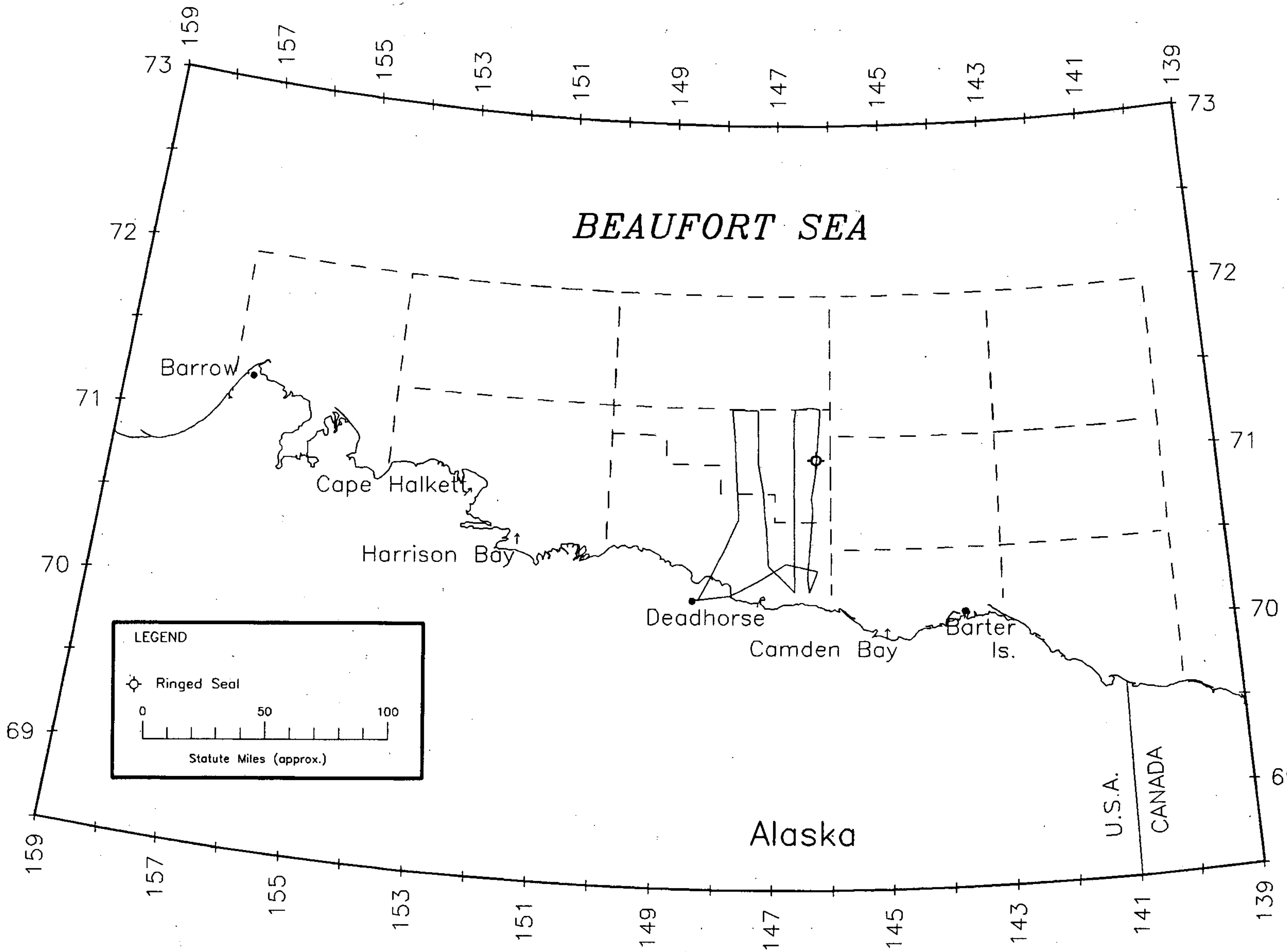
FLIGHT 33 18 October 1993
Survey Track and Sightings



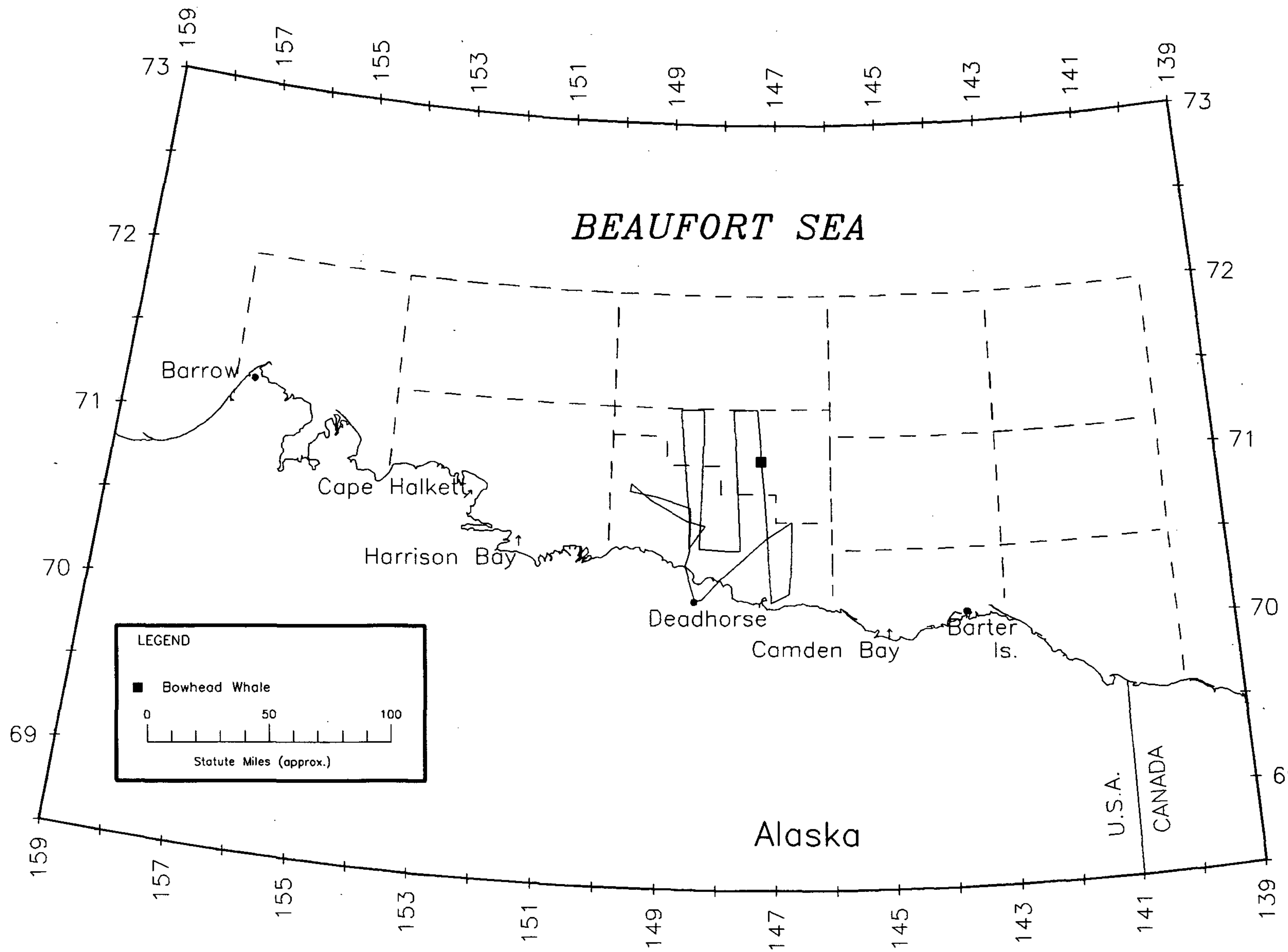
FLIGHT 34 19 October 1993
Survey Track and Sightings



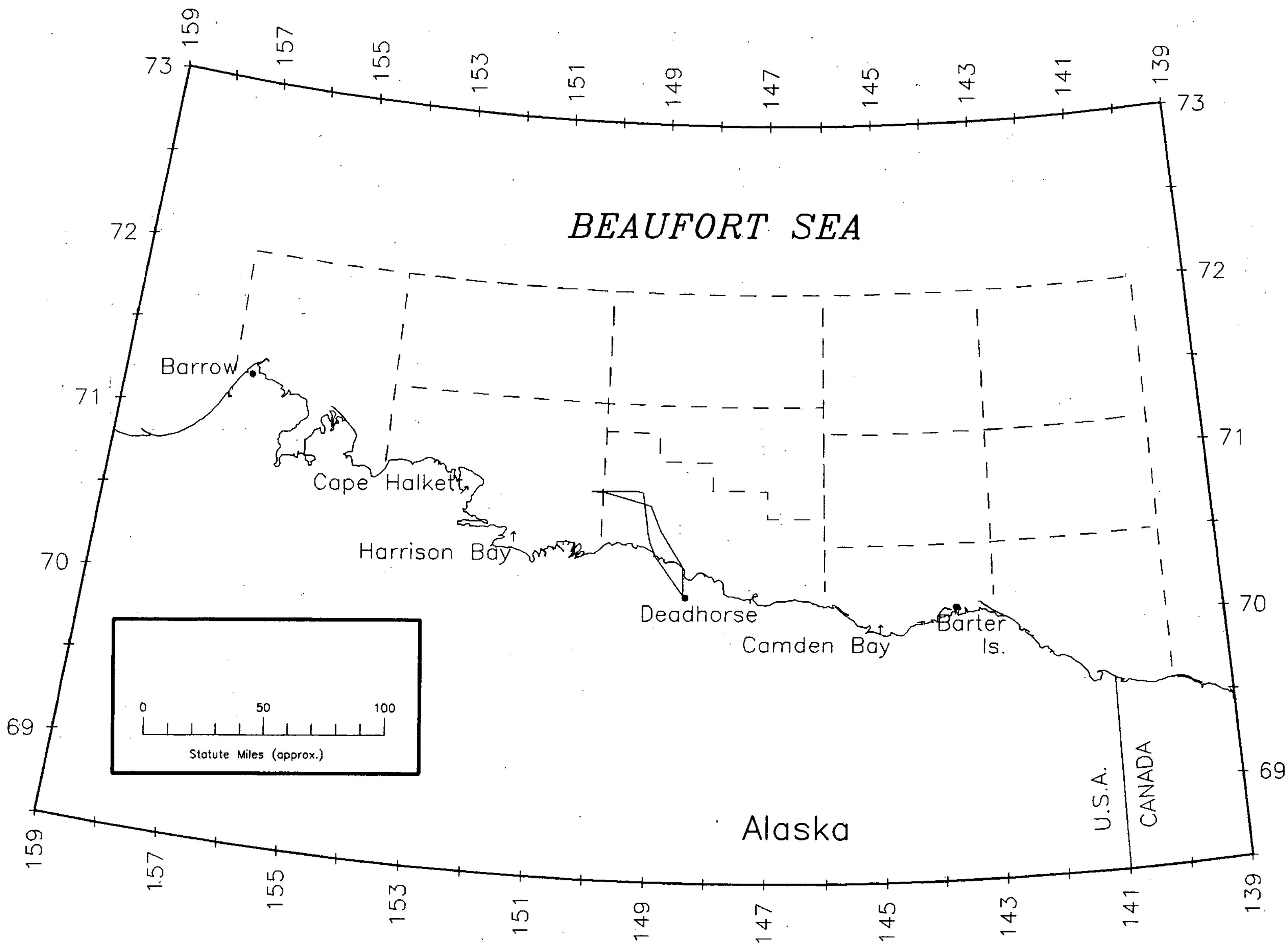
FLIGHT 35 20 October 1993
Survey Track and Sightings



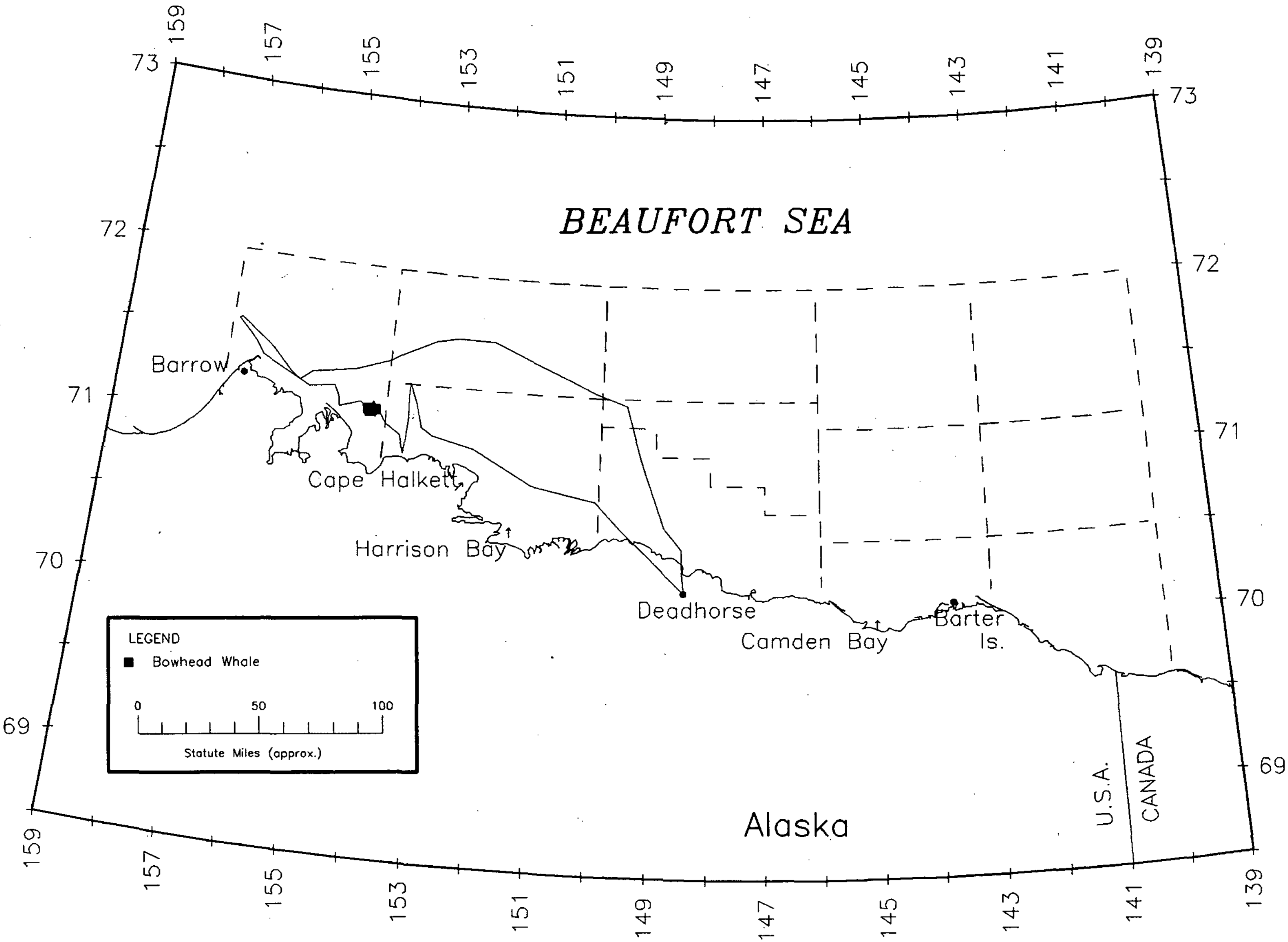
FLIGHT 36 21 October 1993
Survey Track and Sightings



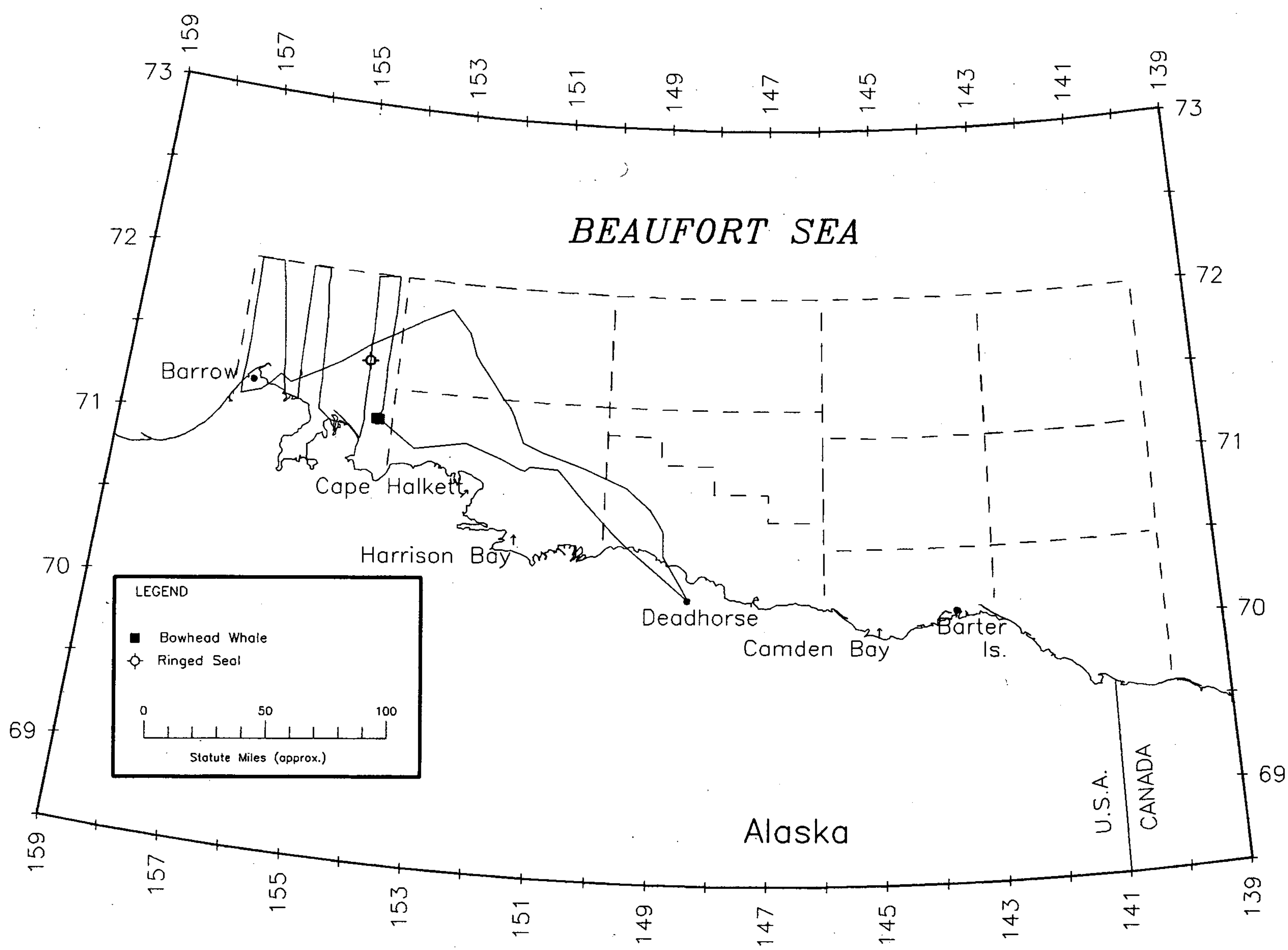
FLIGHT 37 22 October 1993
Survey Track and Sightings



FLIGHT 38 24 October 1993
Survey Track and Sightings



FLIGHT 39 26 October 1993
Survey Track and Sightings



FLIGHT 40 27 October 1993
Survey Track and Sightings

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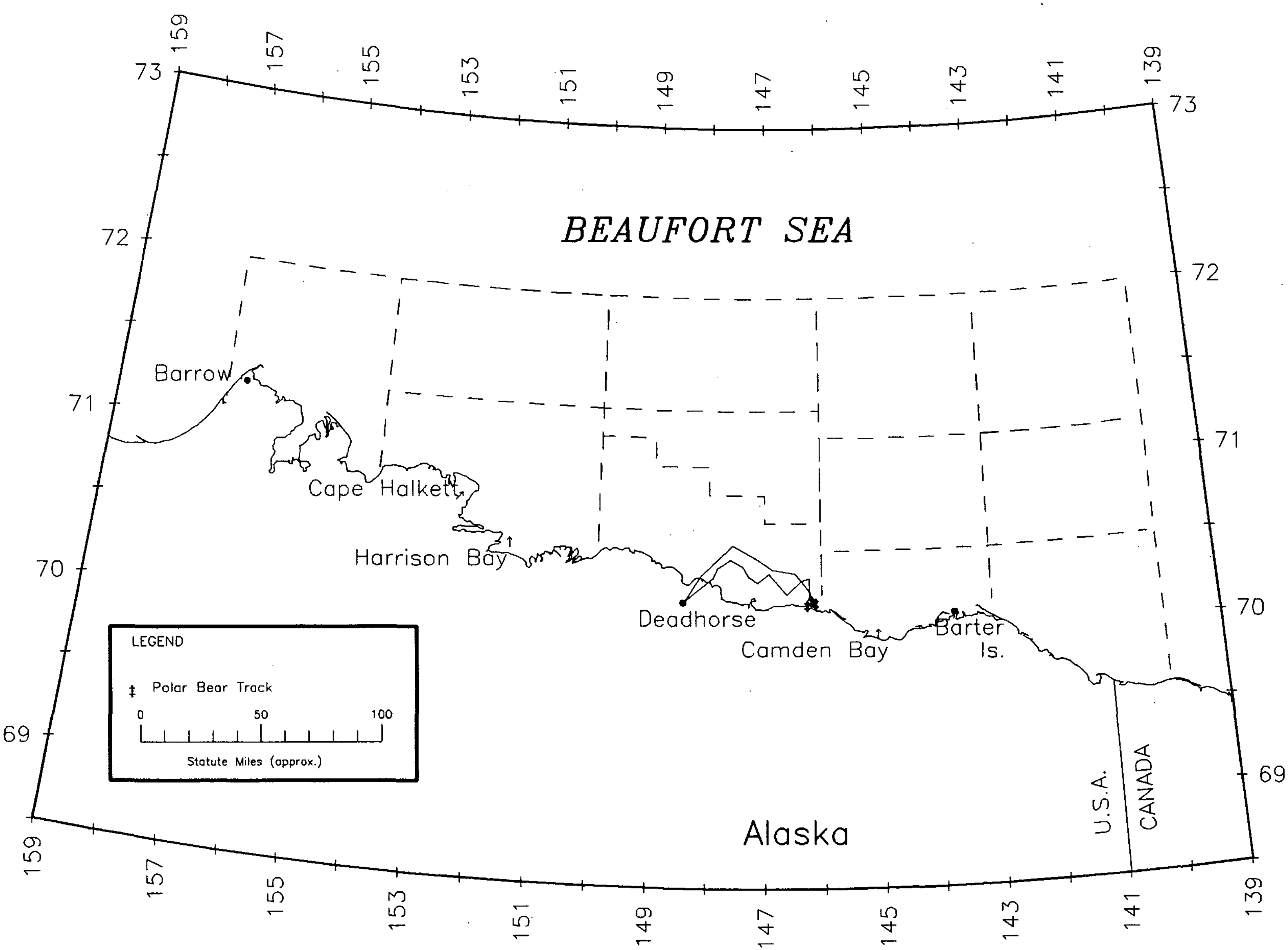

FLIGHT 41 28 October 1993
Survey Track and Sightings

GLOSSARY OF ACRONYMS, INITIALISMS, AND ABBREVIATIONS

AC	alternating current
ANOVA	analysis of variance
BLM	Bureau of Land Management
C	Celsius
CI	confidence interval
ELT	emergency location transmitter
ESA	Endangered Species Act
FMS	Flight Management System
FR	Federal Register
GPS	Global Positioning System
hr	hour
HP	Hewlett-Packard
km	kilometer
m	meter
MDC	Mobile Datacom Corporation
MMS	Minerals Management Service
n	sample size
NOAA	National Oceanic and Atmospheric Administration
NOS	Notice of Sale
NOSC	Naval Ocean Systems Center
NMFS	National Marine Fisheries Service
nm	nautical miles
OAS	Office of Aircraft Services
OCS	Outer Continental Shelf
OCSLA	Outer Continental Shelf Lands Act
p	probability
RDSS	Radio Determination Satellite System
SD	standard deviation
SPUE	sightings per unit effort (number of whale sightings counted per hour)
T	true heading
USC	U.S. Code
USDOC	U.S. Department of Commerce
USDOD	U.S. Department of Defense
USDOI	U.S. Department of the Interior
WPUE	whales per unit effort (number of whales counted per hour); relative abundance

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interest of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.