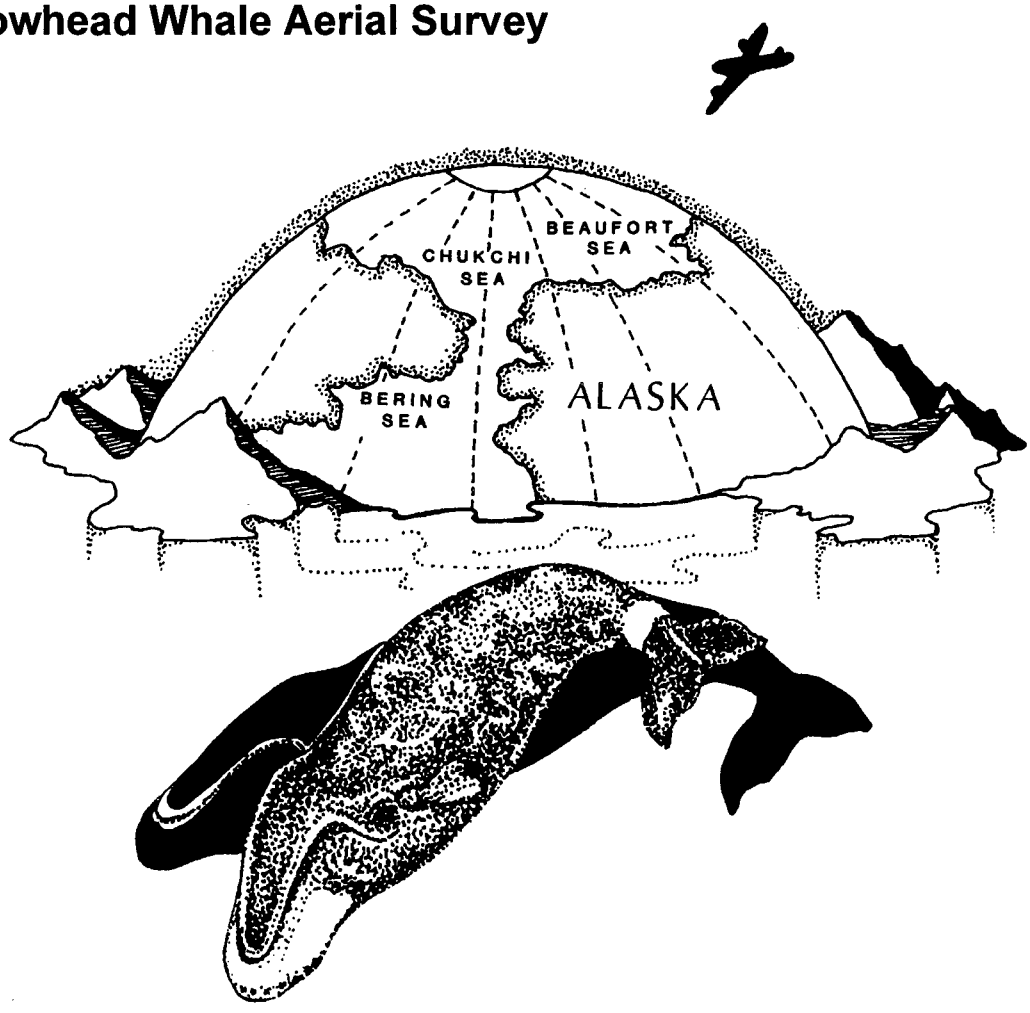
Aerial Surveys of Endangered Whales in the Beaufort Sea, Fall 1998-1999

OCS Study
MMS 2000-066

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



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Minerals Management Service
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ABSTRACT

This report describes field activities and data analyses for aerial surveys of bowhead whales conducted during Fall 1998 (31 August-27 October) and Fall 1999 (31 August-23 October) in the Beaufort Sea, primarily between 140°W. and 157°W. longitudes south of 72°N. latitude.

During Fall 1998, general ice cover during September and October was the third-mildest open-water season (1979-1999), with the 5-tenths ice-concentration boundary 240 nm north of Point Barrow in September. The very high number of sightings of bowhead whales (n=383) as well as the very high number of individual bowhead whales counted (n=1,045) likely resulted from favorable open-water conditions along with some potential repeat counting between days of large aggregations of feeding and/or milling whales that appeared to remain in the same area for several days. A total of 1,045 bowhead whales, 5 gray whales, 306 beluga whales, 38 bearded seals, 938 ringed seals, 3 Pacific walrus, 20 unidentified pinnipeds, 235 polar bears, and 26 sets of polar bear tracks were observed during 180.64 hours of survey effort that included 93.79 hours on randomized transects. The initial sighting of bowhead whales in Alaskan waters occurred on 31 August, when 1 bowhead was sighted swimming due west in Survey Block 1. Of all bowhead whales observed, half (median) had been counted by 22 September. The peak count (mode) of 246 whales also occurred on 19 September. The last sightings of bowhead whales (n=2) in the primary study area were made in Block 4 on 26 October in relatively open-water conditions.

During Fall 1999, general ice cover across during September and October was considered light overall, with high concentrations of ice by mid-October. There were 214 sightings of bowhead whales, for a total of 397 individual whales counted. A total of 397 bowhead whales, 446 beluga whales, 2 gray whales, 1 unidentified cetacean, 81 bearded seals, 1,325 ringed seals, 10 unidentified pinnipeds, 37 polar bears, and 70 sets of polar bear tracks were observed during 114.16 hours of survey effort that included 60.15 hours on randomized transects. The initial sighting of bowhead whales in Alaskan waters occurred on 3 September, when 13 bowheads were observed headed in various directions in Block 4. Of all bowhead whales observed, half (median) had been counted by 17 October. The peak count (mode) of 117 whales occurred on 18 October. The last sightings of bowhead whales (N=17) in the primary study area were made in western Block 12 on 22 October, as 95-100% new sea ice concentrations were forming over almost all of the study area.

The axis of the bowhead whale migration in the West Region during Fall 1998 was closer to shore than in other years. The Tukey HSD test of randomized sightings of bowheads between pairs of years showed that the Fall-1998 migration corridor was significantly nearer to shore in both the East and West Regions of Alaskan Beaufort Sea than in 1999, a year with no offshore seismic exploration or drilling activity during September or October. The relatively small median distances from shore and median water depths at bowhead sightings in Fall 1998 and 1999 in the West Region are consistent with a tendency for bowheads to migrate closer to shore and in shallower water during years of light general ice cover.

ACKNOWLEDGMENTS

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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). The Arctic Region Biological Opinion was used by NMFS for subsequent sales in the Beaufort Sea (Sale 124 in 1991 and Sale 144 in 1996). 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). Three subsequent lease sales in the Beaufort Sea, Sale 97 (1988), Sale 124 (1991), and Sale 144 (1996), have not included a seasonal drilling restriction. The NOS for each of these sales contains an Information to Lessees clause that "MMS intends to continue its areawide endangered whale monitoring program in the Beaufort Sea during exploration activities" (USDOI, MMS, 1988, 1991, 1996). The information gathered will provide additional assistance to determine the extent, if any, of adverse effects on the species.

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 fieldwork 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, Resource Center, 949 East 36th Avenue, Anchorage, Alaska 99508-4363.

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 limitations on seasonal drilling and 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. Define the axis of the fall bowhead migration and analyze for significant interyear differences and long-term trends in the distance from shore and water depth at which whales migrate;

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 beluga 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 has been based on a design of random field transects within established geographic blocks overlapping or near Chukchi and Beaufort Sea sale areas offshore of Alaska. The present study, which was focused on the fall bowhead whale migrations during 1998 and 1999, 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). There is recent evidence for the existence of two regimes or climate states for arctic atmospheric-ice-ocean circulation. Based on analysis of modeled sea level and ice motion, wind-driven motion in the Arctic was found to alternate between anticyclonic and cyclonic circulation, with each regime persisting for 5-7 years (Proshutinsky and Johnson, 1997; Johnson et al., 1999).

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 from -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).

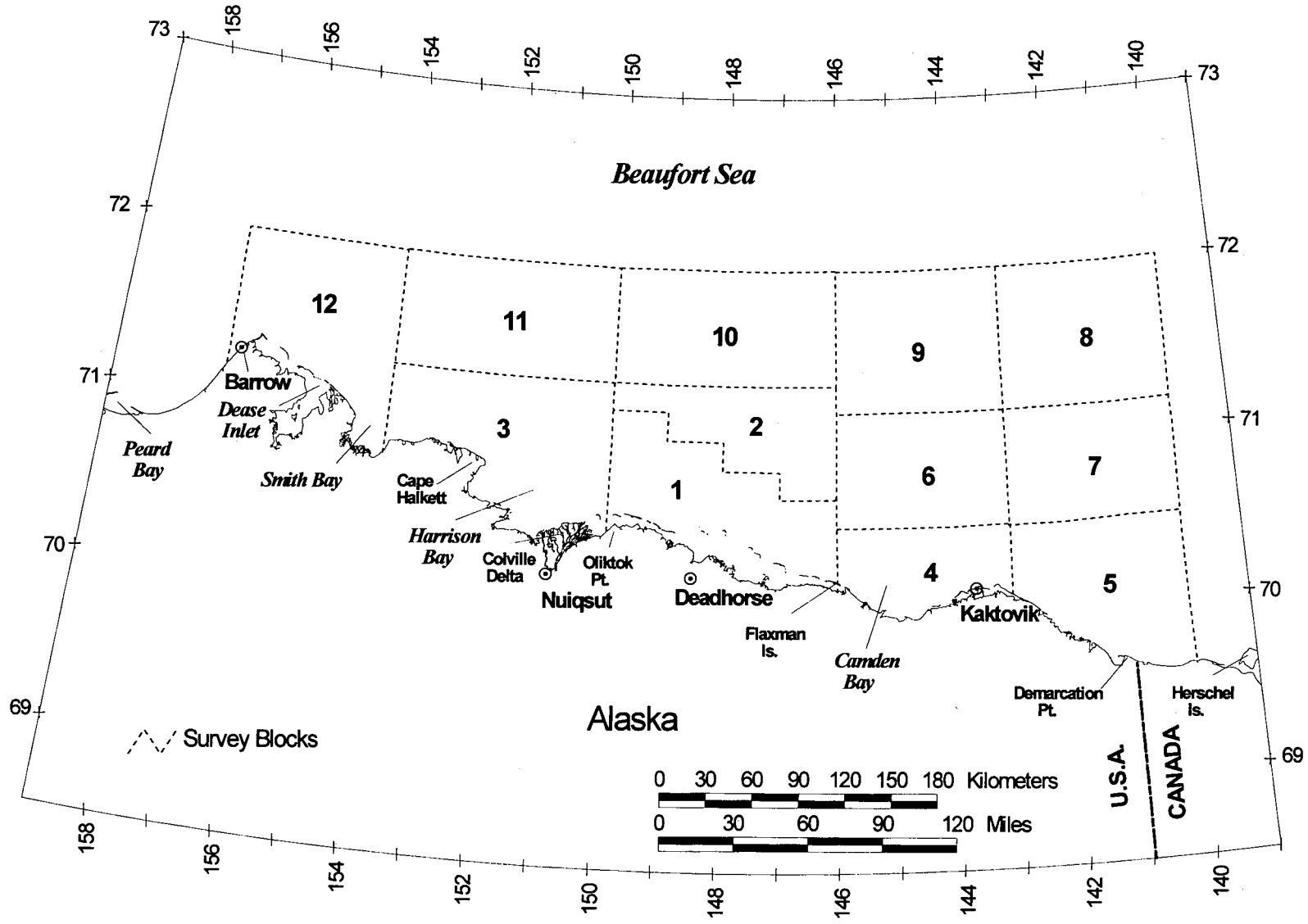

Figure 1. Study Area Showing Survey Blocks

B. Equipment

The survey aircraft was a de Havilland Twin Otter Series 300 (call sign: N321EA). The aircraft was equipped with two medium-size bubble windows behind the cabin bulkhead and one on the aft starboard side that afforded complete trackline viewing. The pilot and copilot seats provided 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.

A portable Gateway Solo 5100 SE laptop computing system was used aboard the aircraft to store and analyze flight and observational data. The computer system was connected to a local Garmin III Global Positioning System (GPS) with external aircraft antenna. Latitude, longitude, and flight altitude from the GPS were transmitted to the computer through a standard serial connection. A custom moving-map program developed by MMS project personnel in Visual Basic permitted surveyors to view the aircraft's trackline in real time.

Onboard safety equipment included an impact-triggered emergency locator transmitter installed in the aircraft, a 6-person Switlik Search and Rescue Life Raft equipped with a portable Personal Locator Beacon and desalination pump, a portable ICOM A3 Sport aircraft-band transceiver, an emergency Magellan 3000 GPS, White dry suits, and emergency flight helmets.

In 1998-99, we used SkyCell satellite flight-following technology for tracking the project aircraft over the Alaskan Beaufort Sea. The OAS obtained current flight information in the form of a map for visual tracking of the survey aircraft. Near the northwestern limit of the satellite coverage area (approx. 156°W. longitude), an aircraft-band very-high-frequency radio was used to transmit periodic position data to Barrow Flight Service. In addition to satellite flight following, the onboard transponder was set at a discrete identification code for radar tracking by air-traffic-control personnel.

C. Aerial-Survey Design

Aerial surveys were based out of Deadhorse, Alaska, from 31 August through 27 October during 1998 and from 31 August through 23 October during 1999. Field schedules were designed to monitor the progress of fall bowhead migrations across the Alaskan Beaufort Sea. All bowhead (and beluga) whales observed were recorded, along with incidental sightings of other marine mammals. Particular emphasis was placed on regional surveys to assess large-area shifts in the migration pathway of bowhead whales and on the coordination of effort and management of data necessary to support seasonal offshore-drilling and seismic-exploration regulations.

Daily flight patterns were based on sets of unique transect grids computer-generated 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 then connected by a straight line to a similarly selected endpoint along the southern edge of that same section. This procedure was followed for all sections of that survey block. These 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 subsequent analyses of the bowhead migration corridor based on line-transect theory (Cochran, 1963).

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 and the level of offshore oil industry activity in various areas. Weather permitting, the project attempted to distribute effort fairly evenly east-to-west across the entire study area. It also used a semimonthly flight-hour goal for each survey block 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,

detailed in our Project Management Plans (USDOI, MMS, 1998 and 1999), 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. Only data from random-transect legs were used to analyze the migration axis, using a line-transect model.

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. Weather permitting, this altitude was maintained in order to maximize visibility and to minimize potential disturbance to marine mammals. Flights were normally aborted when cloud ceilings were consistently less than 305 m or the wind force was consistently above Beaufort 4.

Port observers included a Primary Observer, whose field of vision through a bubble window included the trackline directly below the aircraft to the horizon, the Pilot, and an occasional secondary observer-visitor, stationed aft at a flat window. Starboard observers included a Data Recorder-Observer, whose field of vision through a bubble window was particularly focused on guarding the trackline, as well as a Team Leader and a second Pilot, who were alternately stationed at an aft bubble window and the copilot's seat. 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. Any new sightings of whales made while circling were not counted as "on transect." Likewise, sightings made while en route to transect grids were counted as "on search".

E. Data Entry

A customized computer data-entry form developed by MMS project personnel was used to record all data in database format (Access 97). A multi-columnar data table permitted several entries of sighting and position-update data to be logged and edited simultaneously. The data-entry form is menu-driven, facilitating entry of a complete data sequence for sightings of whales. These data included date, time, latitude, longitude, altitude, aircraft heading, reason for entry, species, total number, observer, swim direction (magnetic), clinometer angle, calf number, behavior, sighting cue, predominant size, habitat, swim speed, repeat sighting, and response to aircraft. Reduced data sequences were used when recording other marine mammals. Position-update data on sky conditions, visual impediments, visibility left and right, percent ice coverage, ice type, and wind force were entered at sightings, turning points, when changes in environmental conditions were observed, and otherwise within 10-minute intervals. Entries were simultaneously printed out in hard copy.

The behavior, swim speed, and swim direction for observed whales represent what the pod as a whole was doing at the time it was first sighted. Behaviors were entered into one of 15 categories as noted on previous surveys. These categories—breaching, cow-calf association, diving, feeding, flipper-slapping, log playing, mating, milling, resting, rolling, spy-hopping, swimming, tail-slapping, thrashing, and underwater blowing—are defined in Table 1. 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 was 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). Likewise, whale size was estimated relatively as calf (length less than half of accompanying adult), immature, adult, or large adult. Swim direction was initially recorded in magnetic degrees, using the aircraft's compass.

Table 1
Operational Definitions of Observed Whale Behaviors

Behavior	Definition
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.
Cow-Calf	Calf nursing; cow-calf pairs swimming within 20 m of each other.
Diving	Whale(s) changing swim direction or body orientation relative to the water surface, resulting in submergence; may or may not include lifting the tail out of the water.
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
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.
Log-Playing	Whale(s) milling or thrashing about in association with a floating log.
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.
Milling	Whale(s) swimming slowly at the surface in close proximity (within 100 m) to other whales, often with varying headings.
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 the longitudinal axis, sometimes associated with mating.
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.
Swimming	Whale(s) proceeding forward through the water propelled by tail pushes.
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.
Thrashing	Whale(s) exhibiting rapid flexure or gyration in the water.
Underwater-Blowing	Whale(s) exhaling while submerged, thus creating a visible bubble.

Wind force was recorded according to the Beaufort scale outlined 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 over 1-2 kilometers lateral distance from the aircraft was estimated as a single percentage, regardless of ice type.

F. General Data Analyses

Preliminary field data analysis was performed by a computer program—developed by MMS 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.

Tables showing the number of survey hours flown for individual days, half-months, months, or survey blocks were subject to decimal-rounding errors and may or may not add up to the grand total shown for the entire field season. For greatest accuracy and consistency, the total survey hours shown in tables was calculated separately from the cumulative total minutes flown over the entire field season.

An index of relative abundance was derived as whales per unit effort (WPUE = number of whales counted/hr of survey effort. The timing of the 1998 and 1999 bowhead migrations 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.

The water depth at each bowhead sighting in the 1982-1999 database was derived from the International Bathymetric Chart of the Arctic Ocean (IPCAO) containing grid cells 2.5 km square (website http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/arctic.html. Selected isobaths (10 m, 20 m, 30 m, 40 m, 50 m, 60 m, 100 m, 500 m, 1,000 m, 1,500 m, 2,000 m, 2,500 m, 3,000 m, and 3,500 m), also derived from IPCAO data, were included in Figure 2 for visual reference.

The maps in this report were prepared with application software (ArcView 3.1A) based on Universal Transverse Mercator Zone 6 (central meridian =147°W. longitude, reference latitude 0.00000, false easting 500000.00000, false northing 0.00000, spheroid = GRS 80, scale factor = 0.99960). The natural coastline was adopted from the State of Alaska, Department of Natural Resources.

Sea-ice concentrations were derived from the Beaufort Sea Ice Analysis provided by the National Ice Center in Suitland, Maryland. The Beaufort Sea Ice Analysis shows average ice concentrations over the prior 2- to 3-day period based on visual, infrared, and synthetic-aperture-radar satellite imagery combined with reconnaissance, ship, and shore observations, including sea-ice observations made by the project. Polygons of ice concentrations in the Beaufort Sea bracketing the field seasons were downloaded from the National Ice Center Internet web site for the western Arctic (http://www.natice. noaa.gov) and imported into ArcView. Total sea-ice concentrations, regardless of ice type, were edited from these polygons and specially coded to distinguish 0-percent, 1- to 19-percent, 20- to 39-percent, 40- to 59-percent, 60- to 79-percent, 80- to 94-percent, or 95- to 100-percent ice cover.

Survey effort and observed bowhead distribution were plotted semimonthly over the Beaufort Sea study area. Overall fall sightings of beluga whales, as well as incidental sightings of other marine mammals, were depicted on separate maps. Common and scientific names used for marine mammals in this report are taken from Rice (1998).

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

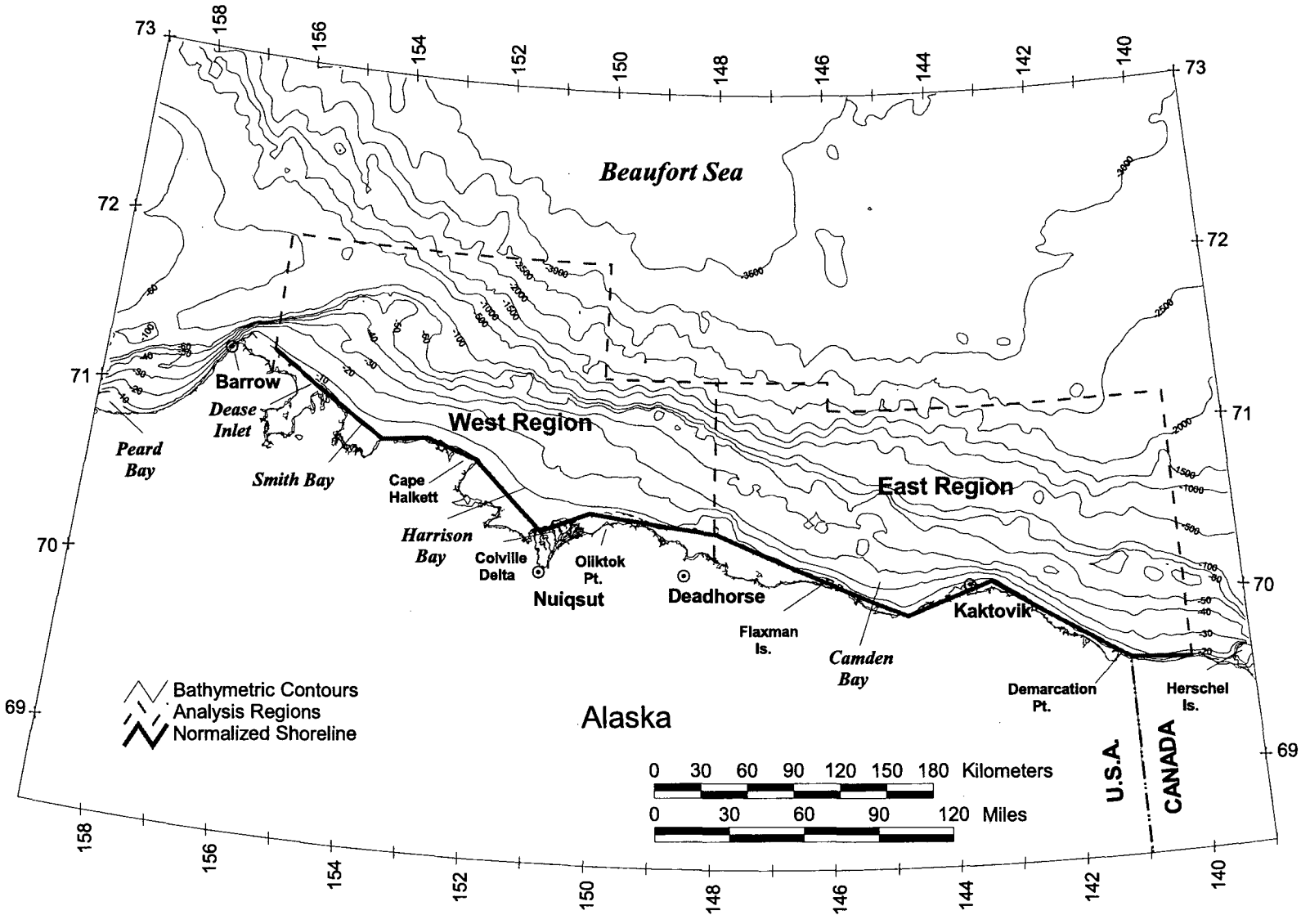

Figure 2. East and West Regions (used in water-depth analyses) and Selected Isobaths

in this series (Treacy, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, and 1998), same-day 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. Analysis of the Bowhead Whale Migration Corridor

The corridor used by bowhead whales during their fall migration was analyzed both by the mean distance from shore to whales sighted on randomized transects as well as mean water depth at random whale sightings. The analyses presented here were completed using *Statistica*™ StatSoft, Version 5.1 and ArcView 3.1A. The mean distance from shore at bowhead sightings between years were compared employing parametric analysis of variance (ANOVA) and Tukey "honestly significant difference" (HSD) tests. The ANOVA tests the hypothesis that distances from shore are the same among years. The Tukey HSD test is a multiple comparison procedure that provides statistical comparison of means for any pair of years (Zar, 1984).

An 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). 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 deeper water and a greater median depth.

Comparing the distance from shore to migrating bowhead whales is another method for detecting shifts in their migratory corridor. Distance from shore is of particular interest to North Slope residents who rely on a successful harvest of whales for subsistence purposes. Subsistence whalers generally agree that the farther offshore whales migrate, the riskier whales are to hunt and the more likely carcasses will spoil before reaching the villages (USDOI, MMS, 1997).

The present analyses provide biological information needed to test the following null hypotheses recommended by the above workshop:

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

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

To determine the usefulness of these analyses for detecting differences in distance from shore between years, a preliminary power analysis was performed (Treacy, 1998).

H. Oceanographic Regions

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. Distance from shore and water depth at bowhead whale sightings made during random transect aerial surveys in the Alaskan Beaufort Sea were analyzed for two regions (Fig. 2), the boundaries of which correspond roughly to oceanographic patterns and the offshore-extent of sampling.

Oceanographic patterns common to waters offshore northern Alaska are reviewed in Moore and DeMaster (1997). In brief, cold saline Bering Sea water and warm fresh Alaskan coastal water enter the Alaskan Beaufort Sea through Barrow Canyon. Both water masses are identifiable on the outer shelf (seaward of 50 m) as the eastward flowing Beaufort undercurrent (Aagaard 1984). Bering Sea water has been traced at least as far east as Barter Island (~143°W.), but the Alaskan coastal water mixes with ambient surface waters as it moves eastward and is not clearly identifiable east of Prudhoe Bay (~147-148°W.). Therefore, the delineation between West-East regions for this analysis occurs at 148°W., based upon association with general patterns for these water masses.

The northern extent of each region is based upon survey effort. For example, the East Region extends from 140°W. to 148°W. and from the shore north to 71°10' N., except between 146°W. and 148°W. where the region extends to 71°20'N. The northern boundary for this region corresponds with boundaries of survey blocks 6, 7 and 2 (Fig. 1): blocks with sufficient survey effort to support analyses (Treacy 1997: Table 11). The West Region extends from 148°W. to 156°W. and from the shore north to 72°N., except between 148°W. and 150°W. where the region extends to 71°20'N. due to the layout of Block 2. The eastern boundary (140°W.) is simply the easternmost longitude of the survey blocks. The western cutoff at 156°W. limits the analysis to bowheads seen in the Alaskan Beaufort Sea and avoids the influence of Barrow Canyon on bowhead depth distribution.

The shoreline used for this analysis was 'normalized' from the actual Beaufort Sea shoreline to provide a standardization of distance-from-shore measures regardless of the mapping software being used to depict the distribution data. The 'normalized' shoreline was derived by connecting, with straight lines, eleven points at various shoreline or barrier islands locations across Alaska's North Slope between 156°W. and 140°W. (Fig. 2). The points used to 'normalize' the shoreline are as follows:

71.317°N., 156.000°W.
70.883°N., 153.900°W.
70.917°N., 153.115°W.
70.817°N., 152.200°W.
70.430°N., 151.000°W.
70.550°N., 150.167°W.
70.450°N., 147.950°W.
69.967°N., 144.700°W.
70.150°N., 143.250°W.
69.650°N., 141.000°W.
69.617°N., 140.000°W.

III. FALL 1998 RESULTS

A. Environmental Conditions

General ice coverage in the Alaskan Beaufort Sea (Appendix A) was extremely light during most of the Fall 1998. Light shorefast ice concentrations (20-39%) first appeared by 2 October near Kaktovik. A strip of nearshore ice progressed from light to very heavy (80-94%) concentrations between Kaktovik and Barrow by mid-October. By 23 October, light nearshore ice concentrations (20-39%) extended east into Canada and near-solid (>94%) sea ice had begun to occupy the northeast corner of the study area. Ice percentages and sea states at each sighting of endangered whales are shown in Appendix C (Table C-1).

Environmental conditions permitted 44 flights during Fall 1998. The weather was notably poor (high sea states and/or low cloud ceilings) from 12 through 21 October, permitting only 4.39 total survey hours during that time period (Table 2).

B. Survey Effort

Daily totals of kilometers and hours flown per survey flight during 1998 are shown in Table 2. A total of 40,813 km of surveys were flown in 180.64 hours in the study area at an average speed of 225.94 km/hr. The average survey flight was 927.57 km, with over-ocean flight distances ranging from 148 km to 1,548 km. A total of 21,302 km of random-transect lines were flown in 93.79 hours at an average transect speed of 227.12 km/hr. These random transects constituted 52.19 percent of the total kilometers flown and 51.92 percent of the total flight hours. Survey-flight lines are summarized by semimonthly period in Figures 3 through 7.

On 31 August, survey coverage ranged from 143°W. to 148°W. longitudes, with most of the effort within 30 nautical miles (nm) of shore (Fig. 3). There were 0.57 hours of random transects flown out of 2.12 total flight hours during this period (Table 2), constituting 0.1 percent and 1.2 percent, respectively, of the total time spent in those effort categories.

During the first half of September, survey coverage ranged from 140°W. to 157°W. longitudes, with most of the effort within 70 nm of shore (Fig. 4). There were 27.43 hours of random transects flown out of 50.17 total flight hours during this period (Table 2), constituting 29.2 percent and 27.8 percent, respectively, of the total time spent in those effort categories.

During the second half of September, survey coverage ranged from 140°W. to 157°W. longitudes, mostly within 100 nm of shore (Fig. 5). There were 30.56 hours of random transects flown out of 55.19 total flight hours during this period (Table 2), constituting 32.6 percent and 30.6 percent, respectively, of the total time spent in those effort categories.

During the first half of October, survey coverage ranged from 140°W. to 157°W. longitudes, mostly within 70 nm of shore (Fig. 6). There were 26.07 hours of random transects flown out of 48.32 total flight hours during this period (Table 2), constituting 27.8 percent and 26.7 percent, respectively, of the total time spent in those effort categories.

From 16 through 27 October, survey coverage ranged from 141°W. to 152°W. longitudes, mostly within 60 nm of shore (Fig. 7). There were 9.16 hours of random transects flown out of 24.84 total flight hours during this period (Table 2), constituting 9.8 percent and 13.8 percent, respectively, of the total time spent in those effort categories.

C. Bowhead Whale (*Balaena mysticetus*) Observations

1. Distribution: Three hundred eighty-three sightings were made for a total of 1,045 bowhead whales observed during Fall-1998 surveys in the study area (Table 3 and Figs. 8-13), not counting definite repeat

Table 2
Aerial-Survey Effort in the Beaufort Sea, 31 August–27 October 1998, by Survey Flight

Day	Flight No.	Transect (km)	Connect (km)	Search (km)	Total (km)	Transect (hr)	Total (hr)
31 Aug	1	126	32	319	477	0.57	2.12
2 Sep	2	0	0	277	277	0.00	1.02
3 Sep	3	256	119	176	550	1.15	2.40
4 Sep	4	523	136	419	1,078	2.28	4.42
7 Sep	5	0	0	220	220	0.00	0.88
9 Sep	6	735	152	484	1,371	3.32	6.27
10 Sep	7	504	35	174	713	1.78	2.72
10 Sep	8	309	107	337	753	1.38	3.13
11 Sep	9	686	138	466	1,289	3.00	5.63
12 Sep	10	436	80	111	627	1.93	2.85
12 Sep	11	500	81	275	856	2.17	3.75
13 Sep	12	748	138	456	1,342	3.33	5.83
14 Sep	13	1,005	193	186	1,385	4.42	6.22
15 Sep	14	599	149	459	1,207	2.67	5.05
16 Sep	15	841	114	246	1,201	3.73	5.37
17 Sep	16	890	195	400	1,485	3.85	6.50
18 Sep	17	812	233	434	1,479	3.48	6.78
19 Sep	18	824	17	680	1,521	3.48	6.75
20 Sep	19	1,041	203	124	1,368	4.48	6.02
21 Sep	20	176	13	176	364	0.75	1.53
22 Sep	21	881	74	338	1,293	3.95	6.17
26 Sep	22	81	16	674	771	0.37	3.80
27 Sep	23	215	77	279	570	0.97	2.57
28 Sep	24	551	123	199	872	2.47	3.90
30 Sep	25	688	191	441	1,320	3.03	5.80
1 Oct	26	511	140	471	1,122	2.23	5.18
2 Oct	27	250	15	120	386	1.08	1.80
2 Oct	28	565	97	52	713	2.48	3.23
4 Oct	29	716	81	278	1,074	3.18	4.77
5 Oct	30	641	133	423	1,197	2.88	5.23
6 Oct	31	24	0	123	148	0.10	0.62
7 Oct	32	243	55	50	347	1.08	1.58
7 Oct	33	184	75	118	377	0.87	1.68
8 Oct	34	472	84	323	879	2.12	3.97
9 Oct	35	621	190	486	1,296	2.82	6.10
10 Oct	36	728	117	456	1,300	3.33	5.87
11 Oct	37	848	144	295	1,288	3.90	5.92
12 Oct	38	0	0	503	503	0.00	2.37
18 Oct	39	0	0	491	491	0.00	2.02
22 Oct	40	752	220	416	1,389	3.32	6.17
23 Oct	41	14	0	489	502	0.07	2.10
25 Oct	42	33	0	567	600	0.12	2.28
26 Oct	43	670	177	417	1,264	3.03	5.67

Table 2
Aerial-Survey Effort in the Beaufort Sea, 31 August–27 October 1998, by Survey Flight

Day	Flight No.	Transect (km)	Connect (km)	Search (km)	Total (km)	Transect (hr)	Total (hr)
27 Oct	44	603	96	849	1,548	2.62	6.60
Semimonthly Effort Summary							
31 Aug		126	32	319	477	0.57	2.12
1-15 Sep		6,301	1,328	4,040	11,668	27.43	50.17
16-30 Sep		7,000	1,256	3,991	12,244	30.56	55.19
1-15 Oct		5,803	1,131	3,698	10,630	26.07	48.32
16-27 Oct		2,072	493	3,229	5,794	9.16	24.84
TOTAL		21,302	4,240	15,277	40,813	93.79	180.64

Table 3
Summary of Marine Mammal Sightings, 31 August-27 October 1998, by Survey Flight
(number of sightings/number of animals)

Day	Flight No.	Bowhead Whale	Gray Whale	Beluga Whale	Unidentified Cetacean	Bearded Seal	Ringed Seal	Pacific Walrus	Unidentified Pinniped	Polar Bear (PB)	PB Tracks (no bear)
31 Aug	1	1/1	0	0	0	0	0	0	0	0	0
2 Sep	2	0	0	0	0	0	0	0	0	0	0
3 Sep	3	1/1	0	4/13	0	1/1	0	0	0	0	0
4 Sep	4	14/17	0	3/5	0	0	9/52	0	2/2	0	0
7 Sep	5	0	0	0	0	0	0	0	0	0	0
9 Sep	6	7/8	0	4/53	0	1/1	1/3	0	1/5	1/9	0
10 Sep	7	7/7	0	1/1	0	0	0	0	0	2/10	0
10 Sep	8	4/4	0	0	0	0	0	0	0	0	0
11 Sep	9	12/22	0	0	0	0	3/13	0	0	2/9	0
12 Sep	10	3/4	0	0	0	0	1/4	0	0	2/11	0
12 Sep	11	9/18	0	0	0	1/1	0	0	0	0	0
13 Sep	12	22/57	0	0	0	2/2	10/81	1/1	0	2/5	0
14 Sep	13	12/13	1/1	1/2	0	1/1	17/163	0	0	1/6	0
15 Sep	14	15/22	0	0	0	5/7	10/244	0	0	1/1	0
16 Sep	15	9/12	0	1/25	0	2/2	5/65	0	0	1/1	0
17 Sep	16	8/10	0	2/42	0	0	1/4	0	0	1/5	0
18 Sep	17	38/56	0	1/1	0	4/5	5/43	0	0	1/5	0
19 Sep	18	16/246	1/1	4/75	0	1/1	2/16	0	0	0	0
20 Sep	19	12/18	0	0	0	3/4	8/79	0	0	0	0
21 Sep	20	3/4	0	0	0	0	0	0	0	0	0
22 Sep	21	8/9	0	0	0	2/2	4/30	0	0	3/8	0
26 Sep	22	1/5	0	0	0	1/1	0	0	0	4/18	0
27 Sep	23	4/4	0	0	0	1/1	0	0	0	1/6	0
28 Sep	24	32/141	1/3	0	0	0	0	0	0	2/2	0
30 Sep	25	46/202	0	0	0	0	0	0	0	0	0
1 Oct	26	3/4	0	0	0	1/1	0	2/2	0	3/20	0
2 Oct	27	0	0	0	0	0	0	0	0	3/3	0
2 Oct	28	2/3	0	0	0	0	0	0	0	0	0

Table 3
Summary of Marine Mammal Sightings, 31 August-27 October 1998, by Survey Flight
(number of sightings/number of animals)

Day	Flight No.	Bowhead Whale	Gray Whale	Beluga Whale	Unidentified Cetacean	Bearded Seal	Ringed Seal	Pacific Walrus	Unidentified Pinniped	Polar Bear (PB)	PB Tracks (no bear)
4 Oct	29	7/9	0	0	0	1/1	0	0	0	0	2
5 Oct	30	23/39	0	3/13	0	0	0	0	0	0	0
6 Oct	31	0	0	0	0	0	0	0	0	0	0
7 Oct	32	1/4	0	0	0	0	0	0	0	0	0
7 Oct	33	4/5	0	0	0	0	0	0	0	0	0
8 Oct	34	5/7	0	0	0	0	0	0	0	1/1	2
9 Oct	35	7/7	0	0	0	3/3	9/56	0	4/5	7/15	6
10 Oct	36	28/62	0	0	0	1/2	8/9	0	1/6	0	0
11 Oct	37	17/22	0	1/75	0	0	4/8	0	1/1	0	1
12 Oct	38	0	0	0	0	0	2/19	0	0	4/13	6
18 Oct	39	0	0	0	0	0	2/5	0	0	13/31	2
22 Oct	40	0	0	0	0	1/1	0	0	1/1	8/31	5
23 Oct	41	0	0	0	0	0	0	0	0	5/17	1
25 Oct	42	0	0	0	0	0	5/35	0	0	0	1
26 Oct	43	2/2	0	0	0	0	1/1	0	0	0	0
27 Oct	44	0	0	1/1	0	1/1	5/8	0	0	1/8	0
Total Semimonthly Sightings											
31 Aug		1/1	0	0	0	0	0	0	0	0	0
1-15 Sep		106/173	1/1	13/74	0	11/13	51/560	1/1	3/7	11/51	0
16-30 Sep		177/707	2/4	8/143	0	14/16	25/237	0	0	13/45	0
1-15 Oct		97/162	0	4/88	0	6/7	23/92	2/2	6/12	18/52	17
16-27 Oct		2/2	0	1/1	0	2/2	13/49	0	1/1	27/87	9
TOTAL		383/1,045	3/5	26/306	0	33/38	112/938	3/3	10/20	69/235	26

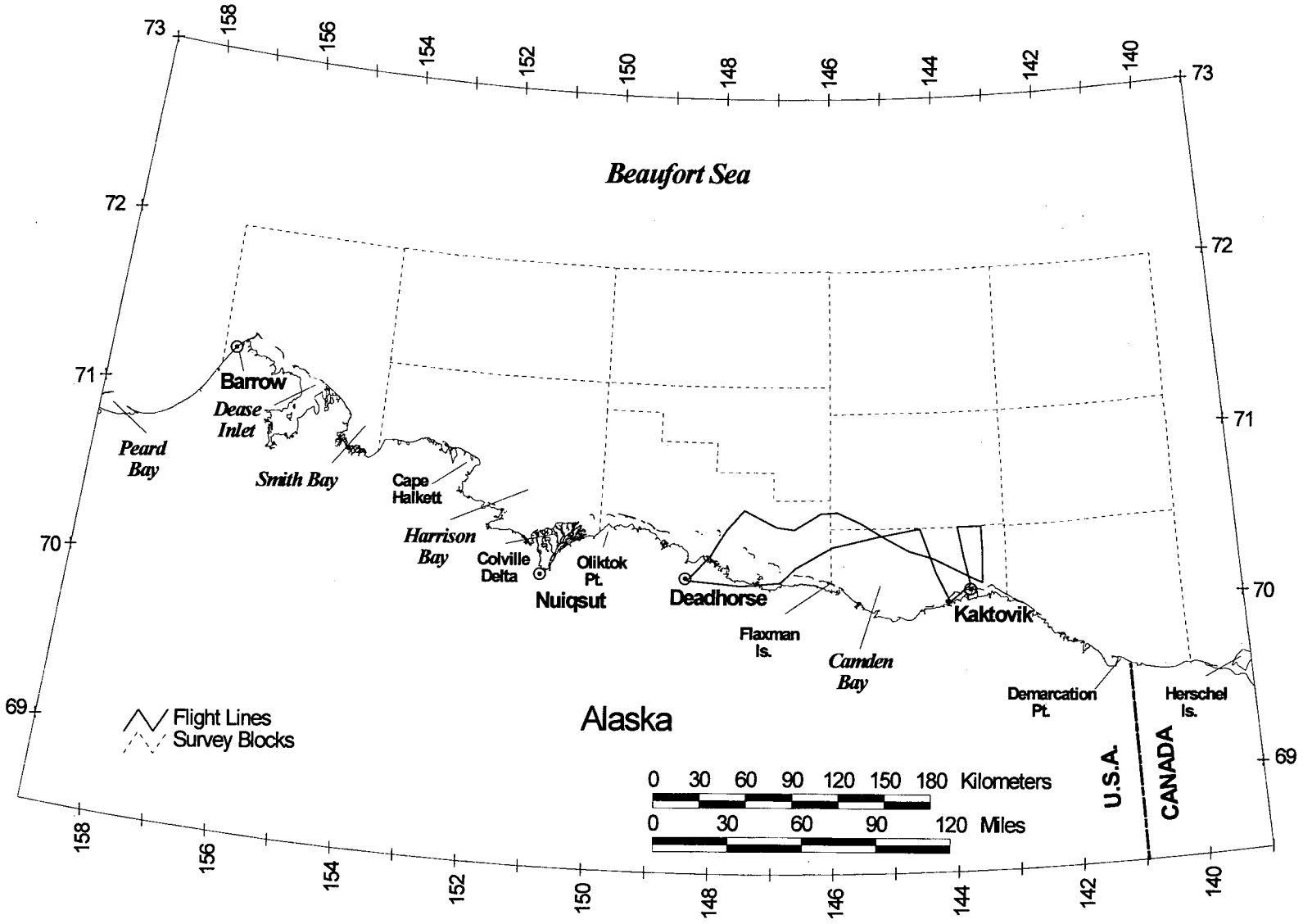

Figure 3. Flight Track, 31 August 1998

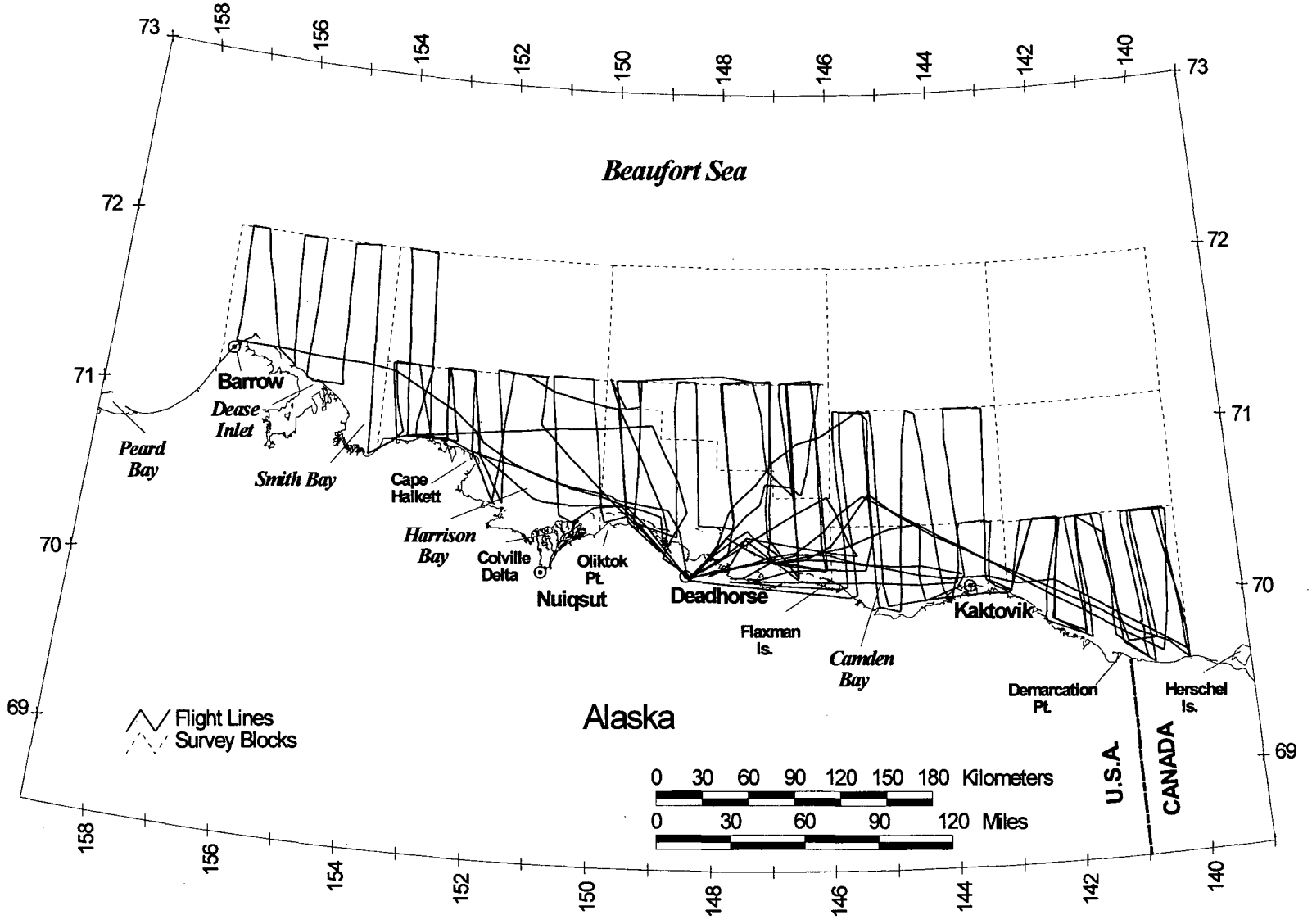

Figure 4. Combined Flight Tracks, 1-15 September 1998

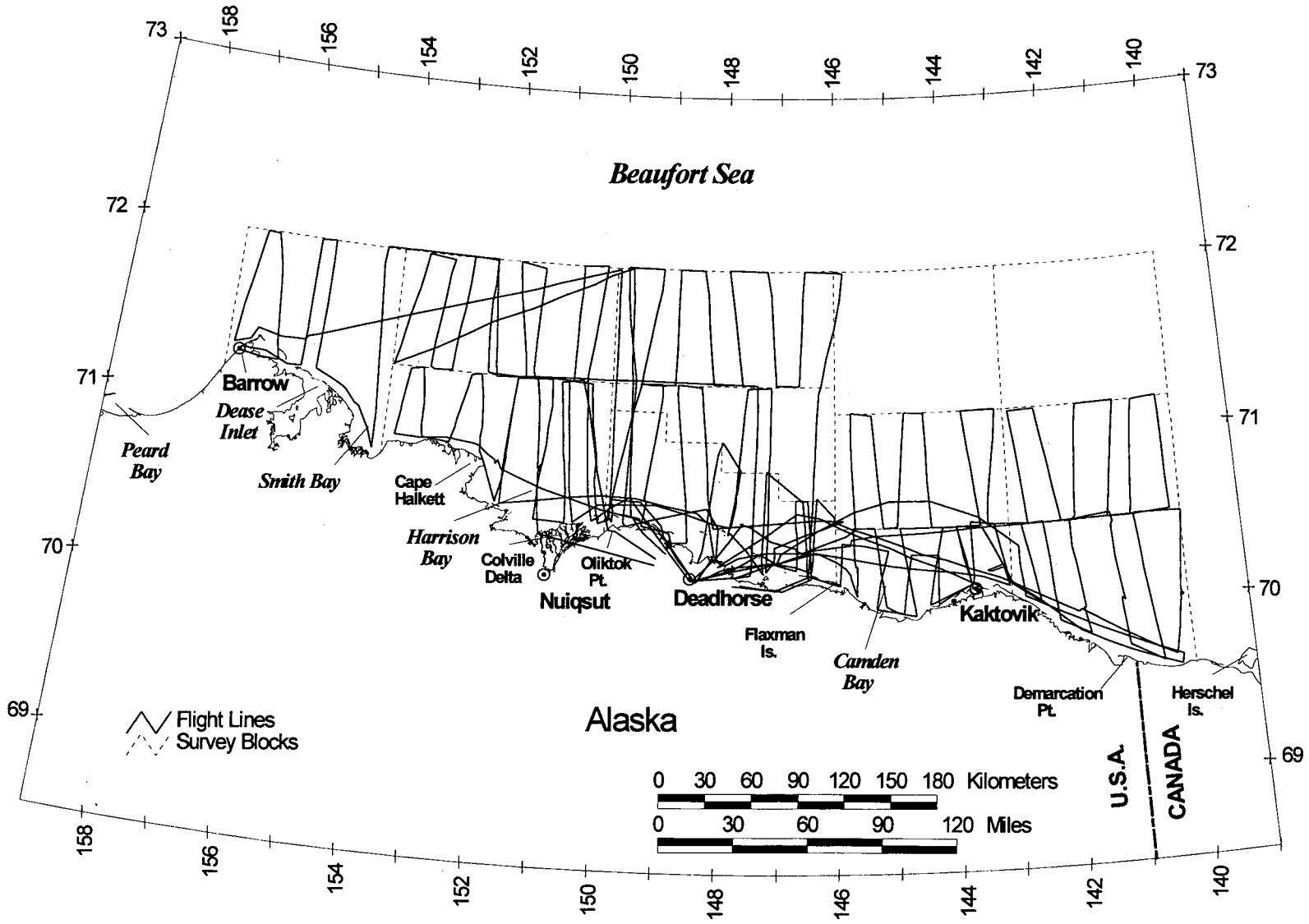

Figure 5. Combined Flight Tracks, 16-30 September 1998

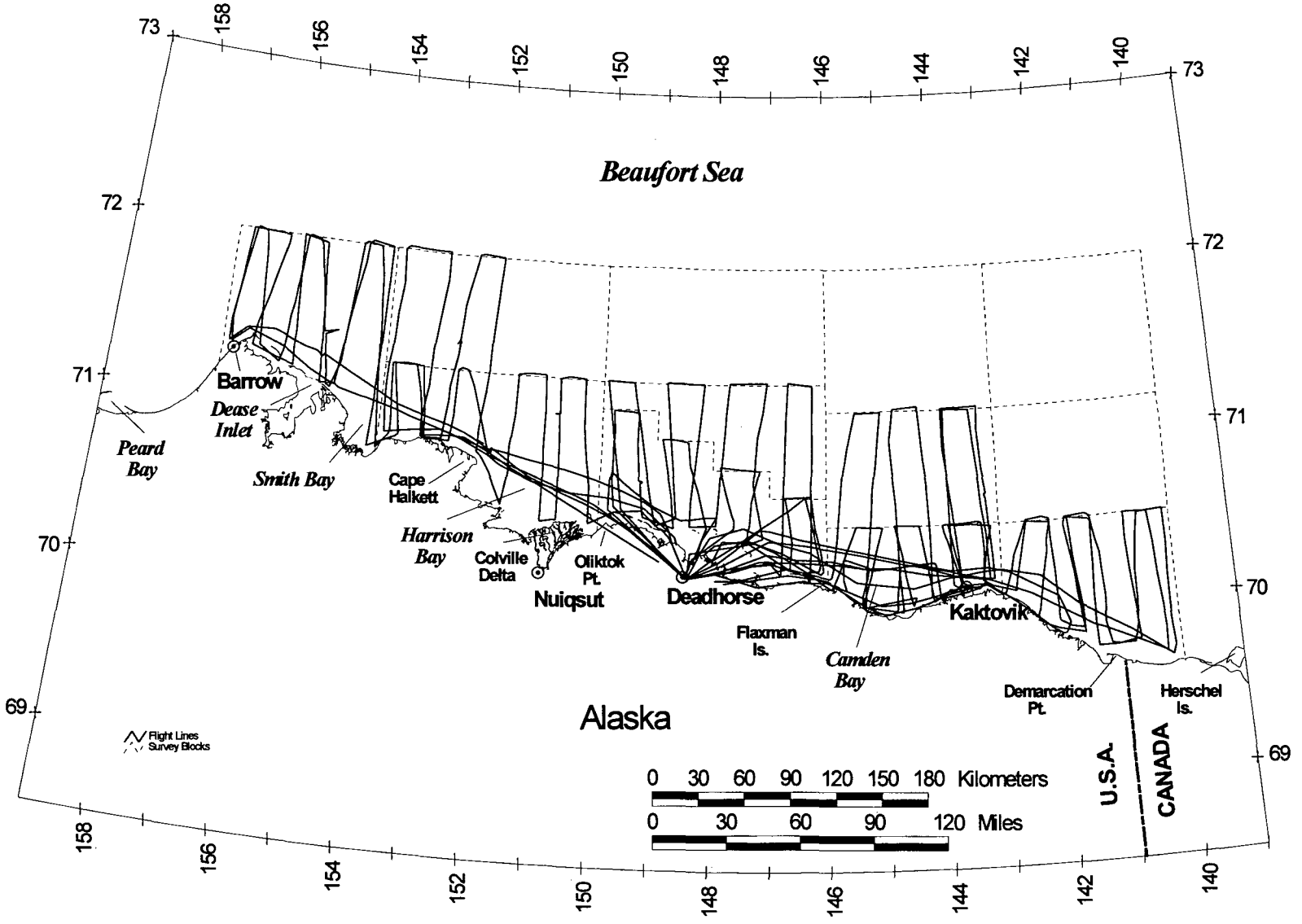

Figure 6. Combined Flight Tracks, 1-15 October 1998

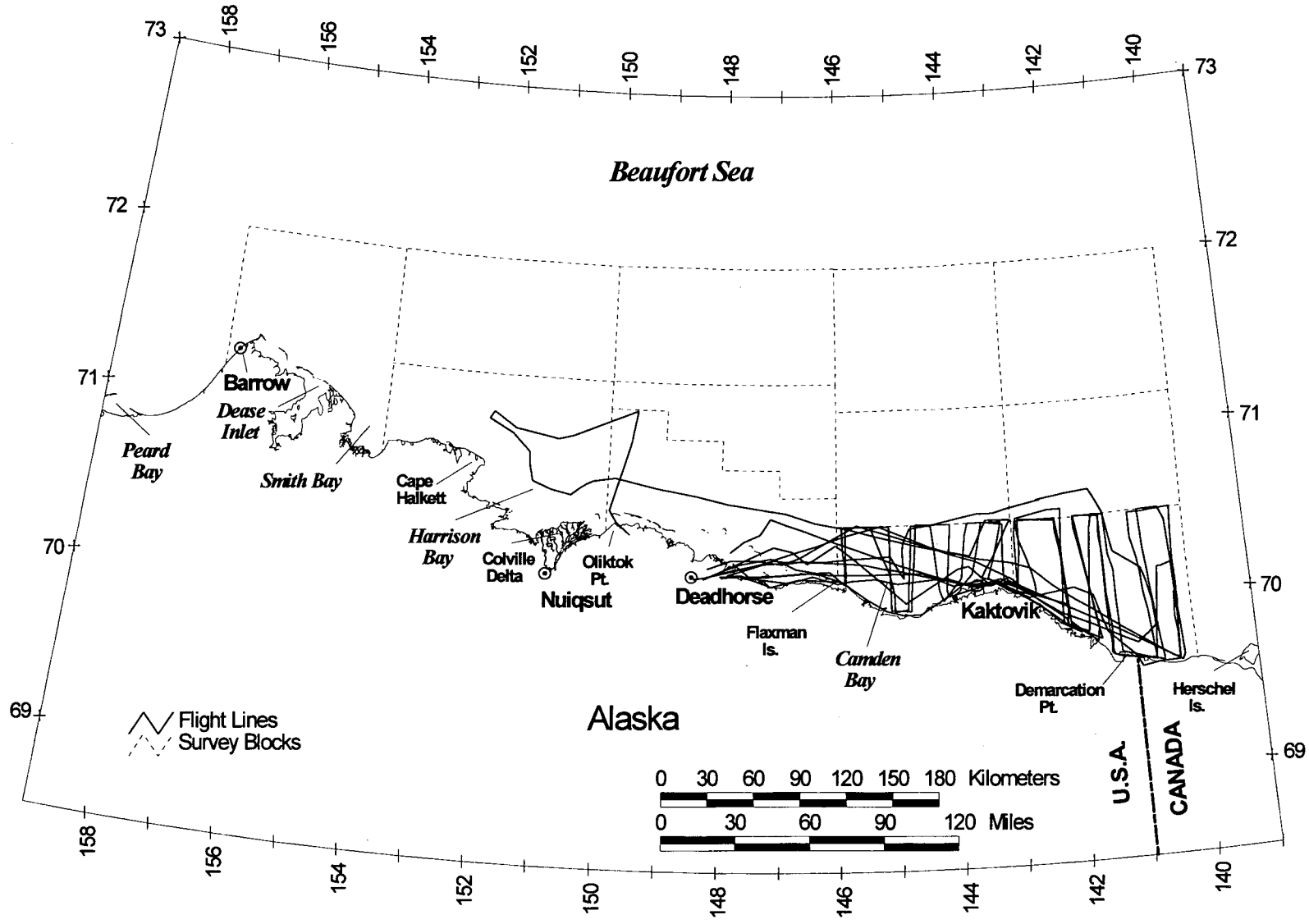

Figure 7. Combined Flight Tracks, 16-27 October 1998

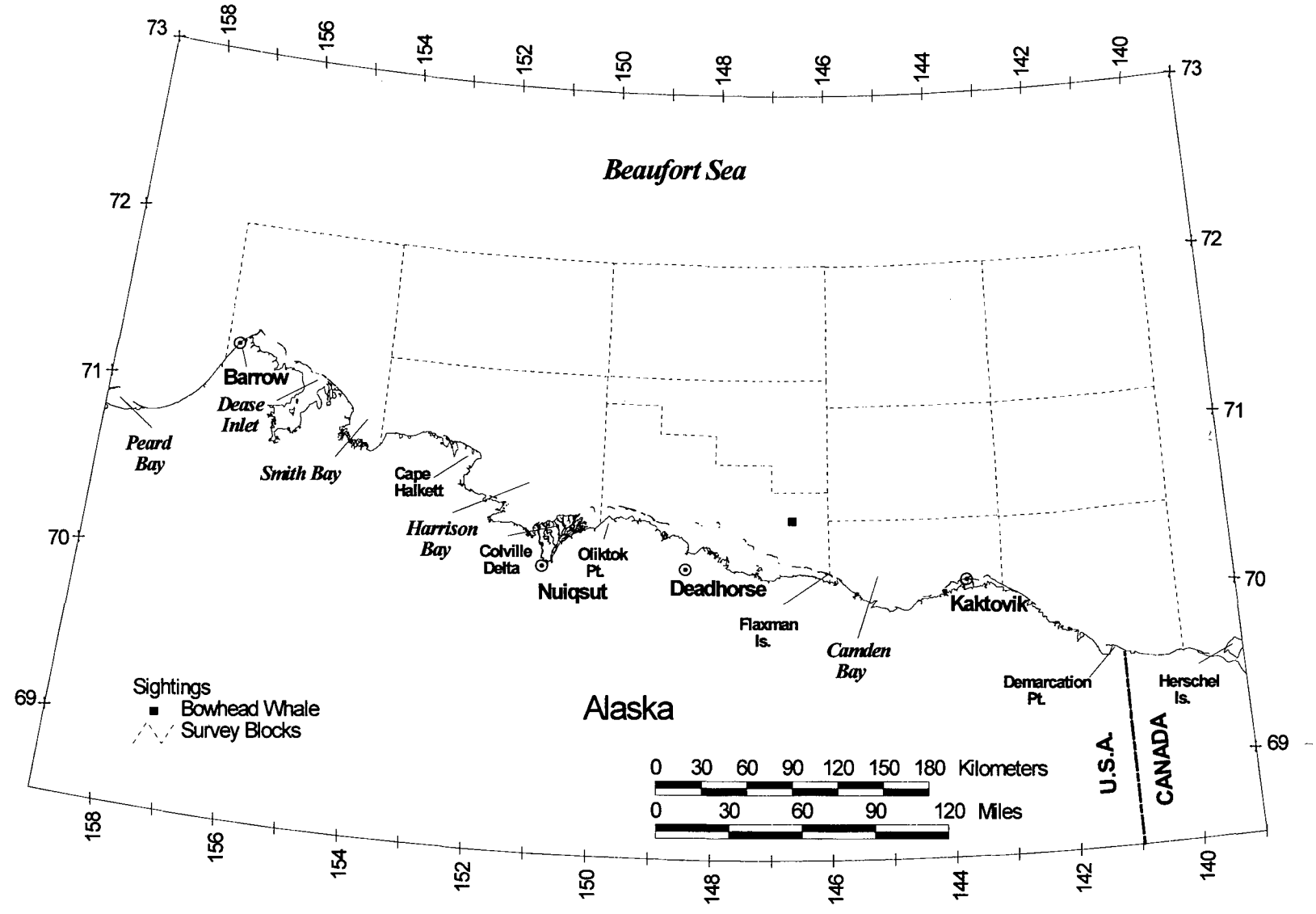

Figure 8. Map of Bowhead Whale Sightings, 31 August 1998

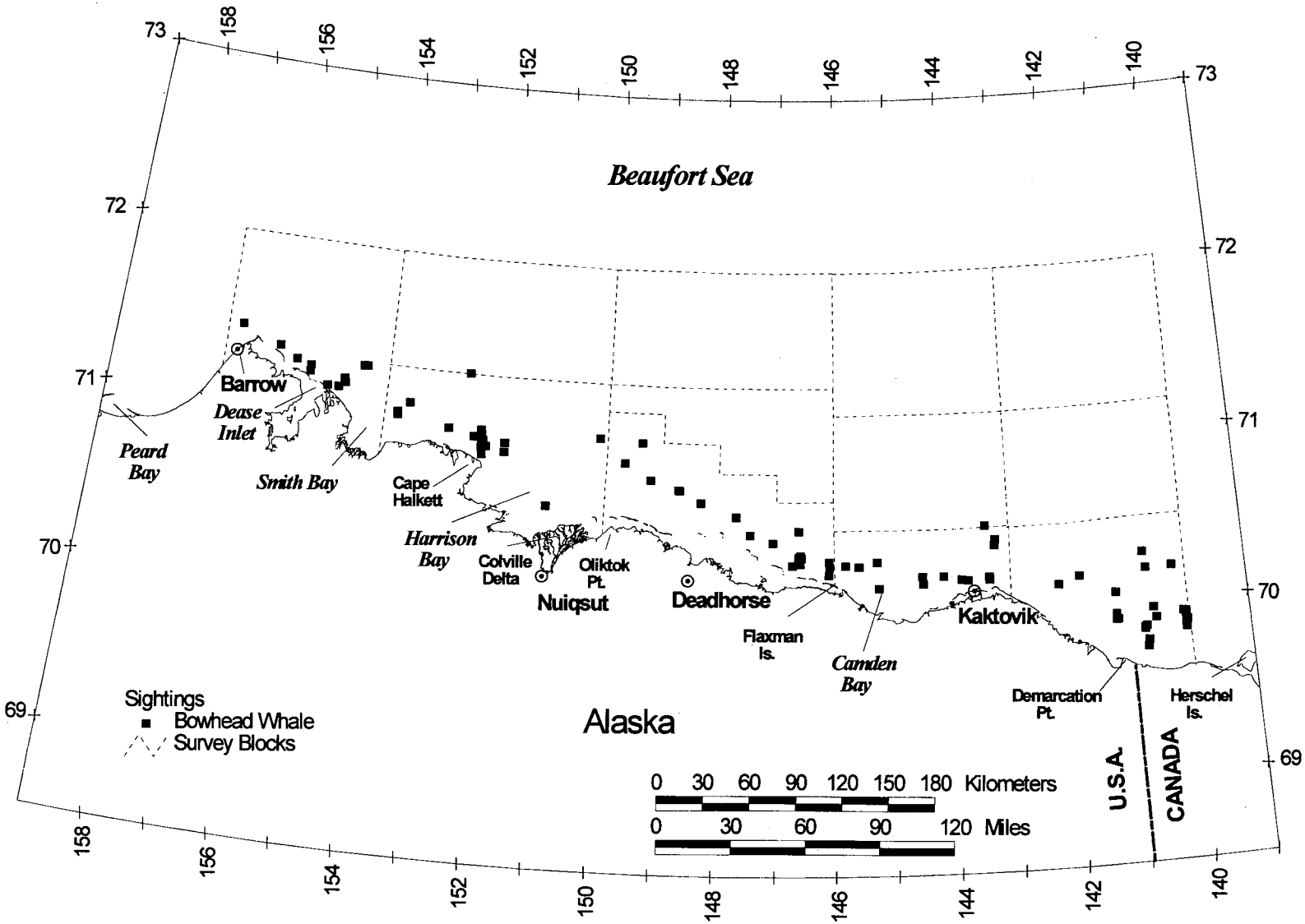

Figure 9. Map of Bowhead Whale Sightings, 1-15 September 1998

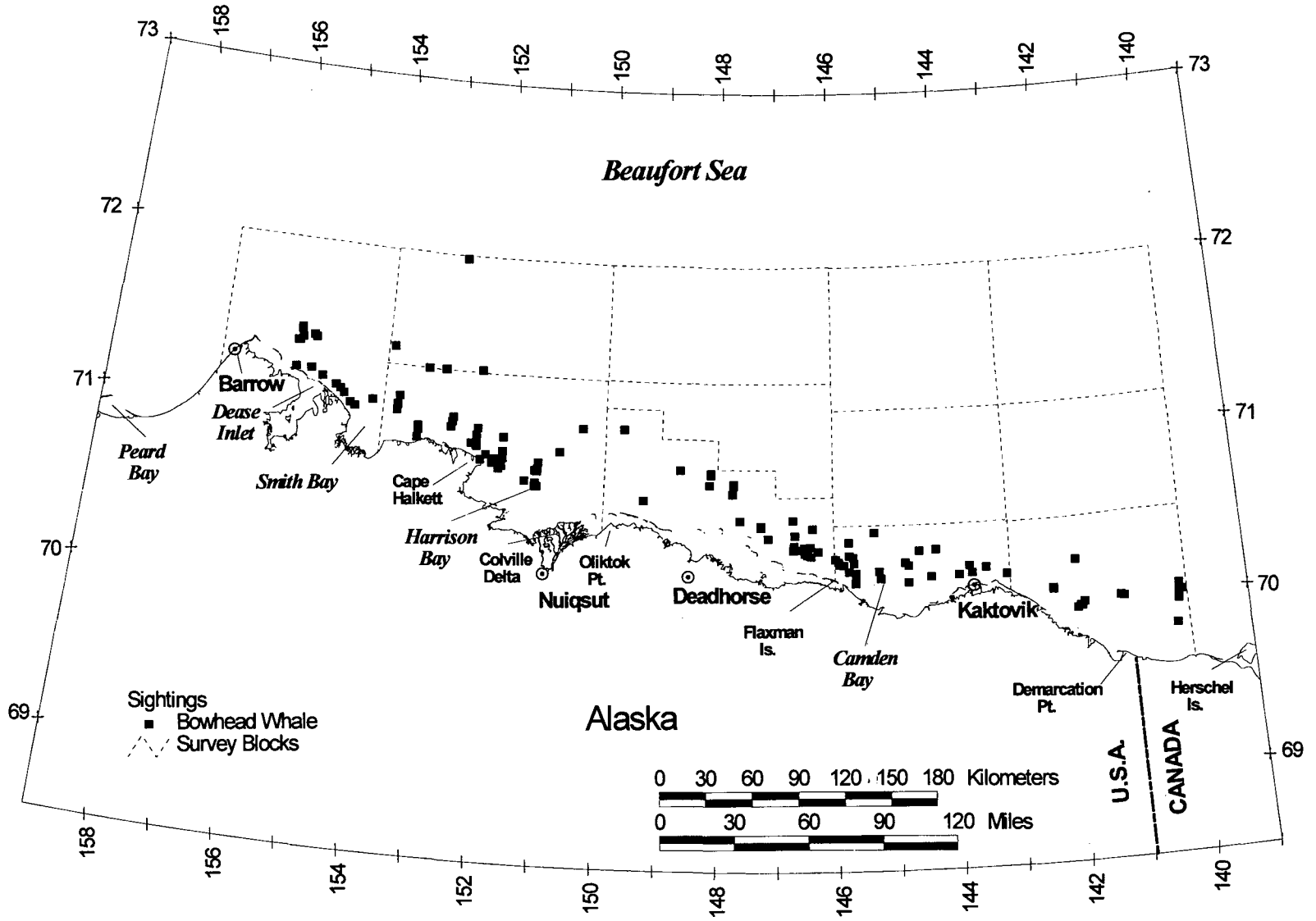

Figure 10. Map of Bowhead Whale Sightings, 16-30 September 1998

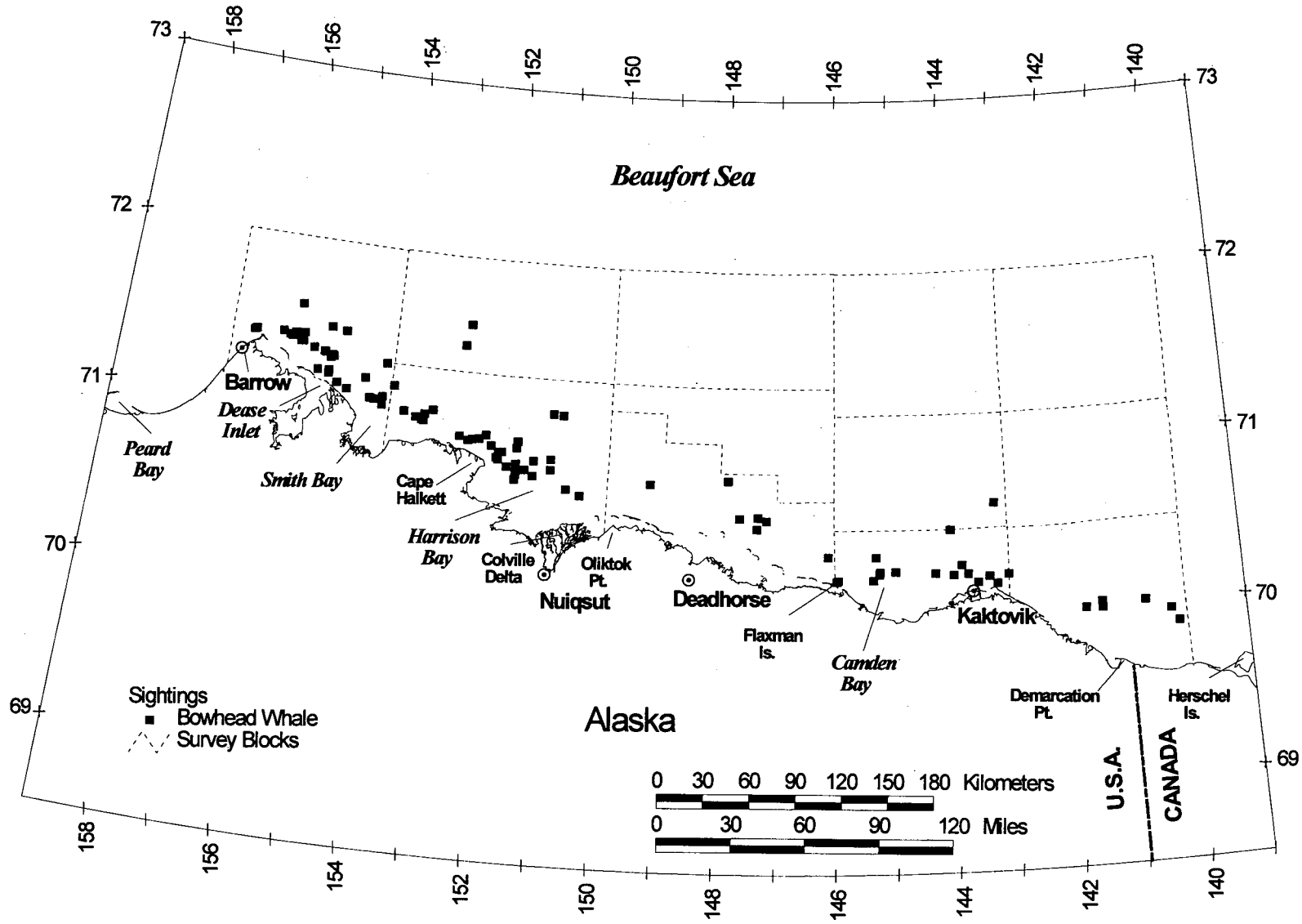

Figure 11. Map of Bowhead Whale Sightings, 1-15 October 1998

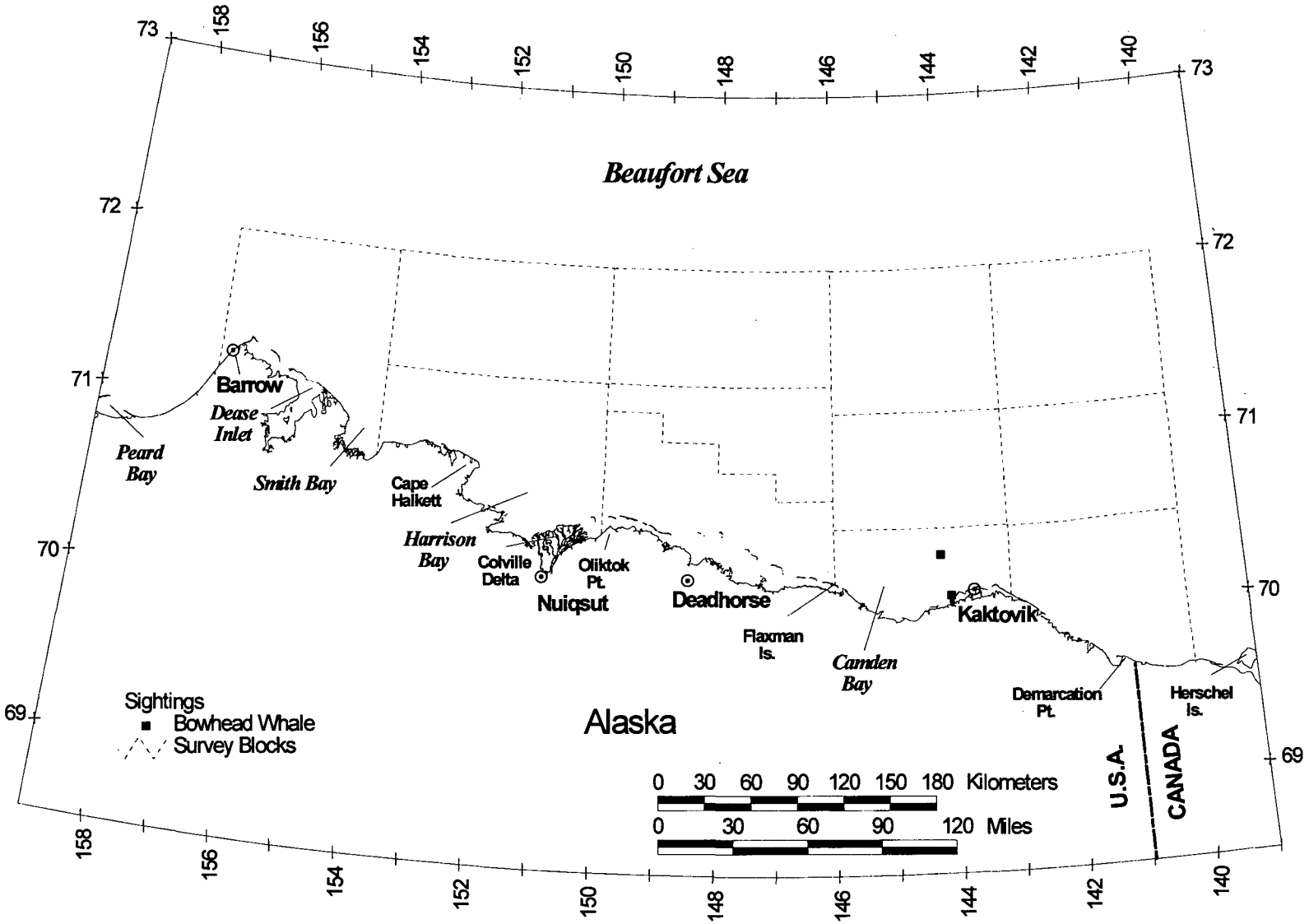

Figure 12. Map of Bowhead Whale Sightings, 16-27 October 1998

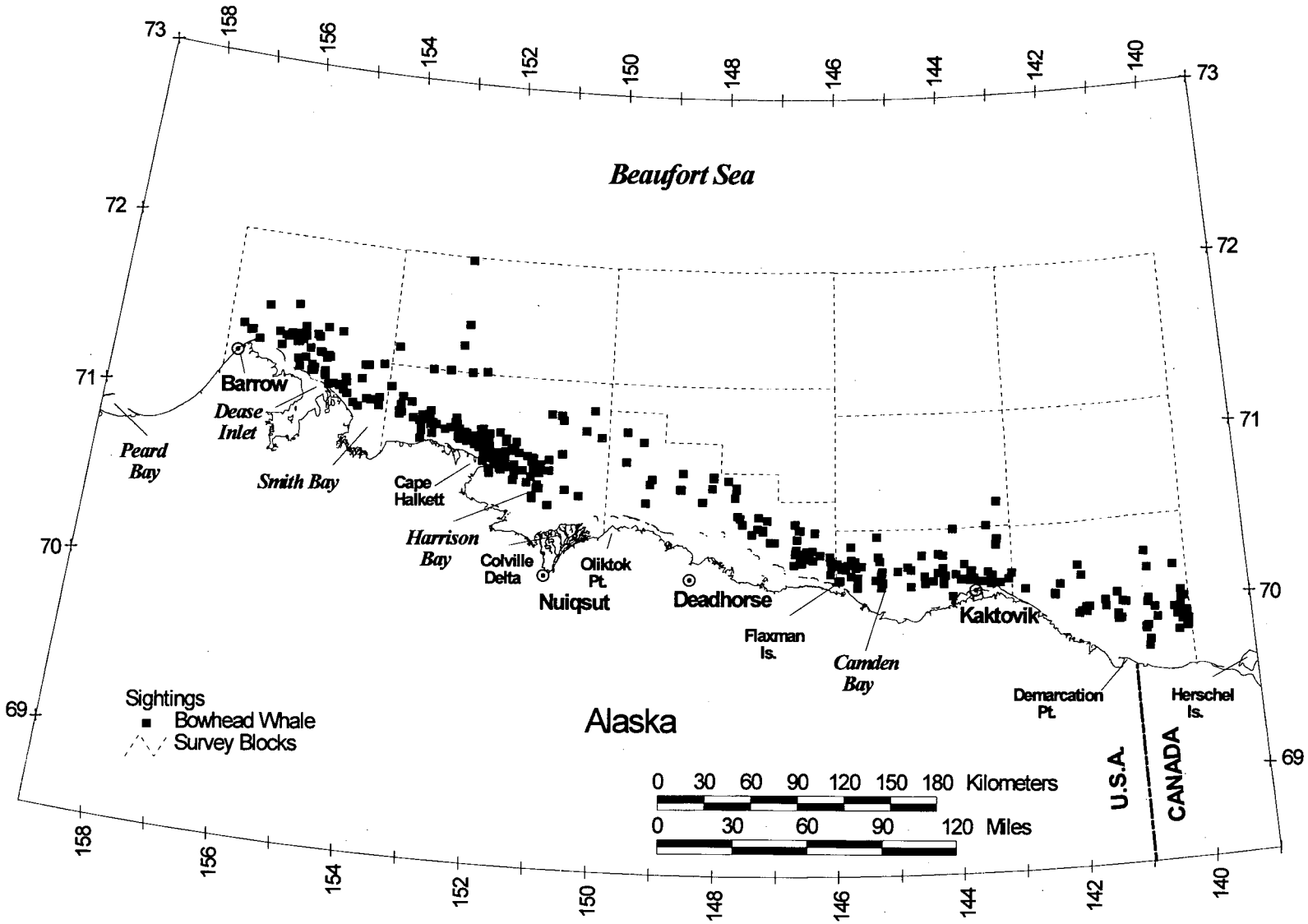

Figure 13. Map of Bowhead Whale Sightings, Fall 1998

sightings or dead whales. The very high number of bowheads was likely a result of favorable open-water conditions along with some potential recounting of large aggregations of feeding and/or milling whales that this year appeared to remain in the same area for several days. Relatively even survey coverage between 140°W. and 157°W. longitudes (Figs. 4-7), resulted in distribution of bowhead whales all across the study area within 40 nm north of the shoreline, with heavier concentrations (unadjusted for effort) between 143°W. and 147°W. and between 151°W. and 156°W. longitudes (Fig. 13). Sixty-two of the 1,044 whales were identified as calves (Appendix C: Table C-1), resulting in a seasonal calf ratio (number calves/total whales) of 0.059. A semi-monthly analysis follows.

On 31 August, one sighting was made for a total of one bowhead whale (Table 3 and Figure 8). This first bowhead observed in the Alaskan Beaufort Sea was sighted at 70°29.9′N. latitude, 146°38.5′W. longitude. No calves were observed that day (Appendix C: Table C-1).

During the first half of September, 106 sightings were made for a total of 173 bowheads (Table 3), with sightings ranging between 140°W. and 157°W. longitudes, based on survey coverage across the study area (Fig. 4). Whale pods were evenly distributed east to west, mostly within 30 nm north of the shoreline (Fig. 9). Pod sizes ranged from 1 to 21 whales, with a mean of 1.63 (SD=2.17, n=106). Four bowhead whale calves were observed during this period (Appendix C: Table C-1).

During the second half of September, 177 sightings were made for a total of 707 bowheads (Table 3), with sightings between 140°W. and 156°W. longitudes, based on survey coverage across the study area (Fig. 5). Whale pods were distributed evenly east to west, mostly within 30 nm north of the shoreline (Fig. 10). Pod sizes ranged from 1 to 78 whales, with a mean of 3.99 (SD=9.47, n=177). Fifty-six bowhead whale calves were observed during this period (Appendix C: Table C-1).

During the first half of October, 97 sightings were made for a total of 162 bowheads (Table 3), with sightings between 140°W. and 157°′W. longitudes, based on survey coverage across the study area (Fig. 6). Whale pods were distributed east to west across the study area, with most pods aggregated between Barrow and the Colville Delta, within 40 nm north of the shoreline (Fig. 11). Pod sizes ranged from 1 to 21 whales, with a mean of 1.67 (SD=2.23, n=97). Two bowhead whale calves were observed during this period (Appendix C: Table C-1).

From 16 through 27 October, 2 sightings were made for a total of 2 bowheads (Table 3), with both sightings just west of 144°′W. longitude, based on survey coverage between 140°W. and 153°W. longitudes (Fig. 7). Both whale pods were located just west of Kaktovik, within 20 nm north of the shoreline (Fig. 12). Pod sizes were each one whale. The last bowhead in the Alaskan Beaufort Sea was sighted at 70°06.3′N. latitude, 144°00.9′W. longitude. No bowhead whale calves were observed during this period (Appendix C: Table C-1).

2. Migration Timing and Relative Abundance: The day-to-day timing of the Fall-1998 bowhead whale migration was calculated over the entire study area (Table 4 and Fig. 14) 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 383 sightings of bowhead whale pods, the first whale observed was on 31 August. The data for daily sighting rates showed a fairly level distribution over the field season, with higher values on 18 September (5.60 SPUE), 28 September (8.21 SPUE), and 30 September (7.93 SPUE). The low values in Figure 14 after 11 October were due in part to few flights and poor weather conditions from 12-21 October. The last sighting of a bowhead whale was made on 26 October (Table 4 and Fig. 14).

Of the 1,045 individual bowhead whales counted, the data for daily relative abundance show that the midpoint (median) of the bowhead migration in Blocks 1 through 12 (when 50% of all sighted whales had been recorded) occurred on 22 September. The peak relative abundance (mode) of 36.44 WPUE occurred on 19 September (Table 4 and Fig. 14).

Table 4
Number of Sightings and Total Bowhead Whales Observed per Hour,
31 August-27 October 1998, by Flight Day

Day	No. of Sightings	No. of Whales	Survey Time (hr)	Sightings/hr (SPUE)	Whales/hr (WPUE)
31 Aug	1	1	2.12	0.47	0.47
2 Sep	0	0	1.02	0.00	0.00
3 Sep	1	1	2.40	0.42	0.42
4 Sep	14	17	4.42	3.17	3.85
7 Sep	0	0	0.88	0.00	0.00
9 Sep	7	8	6.27	1.12	1.28
10 Sep	11	11	5.85	3.85	3.85
11 Sep	12	22	5.63	2.13	3.91
12 Sep	12	22	6.60	3.45	6.20
13 Sep	22	57	5.83	3.77	9.78
14 Sep	12	13	6.22	1.93	2.09
15 Sep	15	22	5.05	2.97	4.36
16 Sep	9	12	5.37	1.68	2.23
17 Sep	8	10	6.50	1.23	1.54
18 Sep	38	56	6.78	5.60	8.26
19 Sep	16	246	6.75	2.37	36.44
20 Sep	12	18	6.02	1.99	2.99
21 Sep	3	4	1.53	1.96	2.61
22 Sep	8	9	6.17	1.30	1.46
26 Sep	1	5	3.80	0.26	1.32
27 Sep	4	4	2.57	1.56	1.56
28 Sep	32	141	3.90	8.21	36.15
30 Sep	46	202	5.80	7.93	34.83
1 Oct	3	4	5.18	0.58	0.77
2 Oct	2	3	5.03	0.62	0.93
4 Oct	7	9	4.77	1.47	1.89
5 Oct	23	39	5.23	4.40	7.46
6 Oct	0	0	0.62	0.00	0.00
7 Oct	5	9	3.26	3.01	5.51
8 Oct	5	7	3.97	1.26	1.76
9 Oct	7	7	6.10	1.15	1.15
10 Oct	28	62	5.87	4.77	10.56
11 Oct	17	22	5.92	2.87	3.72
12 Oct	0	0	2.37	0.00	0.00
18 Oct	0	0	2.02	0.00	0.00
22 Oct	0	0	6.17	0.00	0.00
23 Oct	0	0	2.10	0.00	0.00
25 Oct	0	0	2.28	0.00	0.00
26 Oct	2	2	5.67	0.35	0.35
27 Oct	0	0	6.60	0.00	0.00

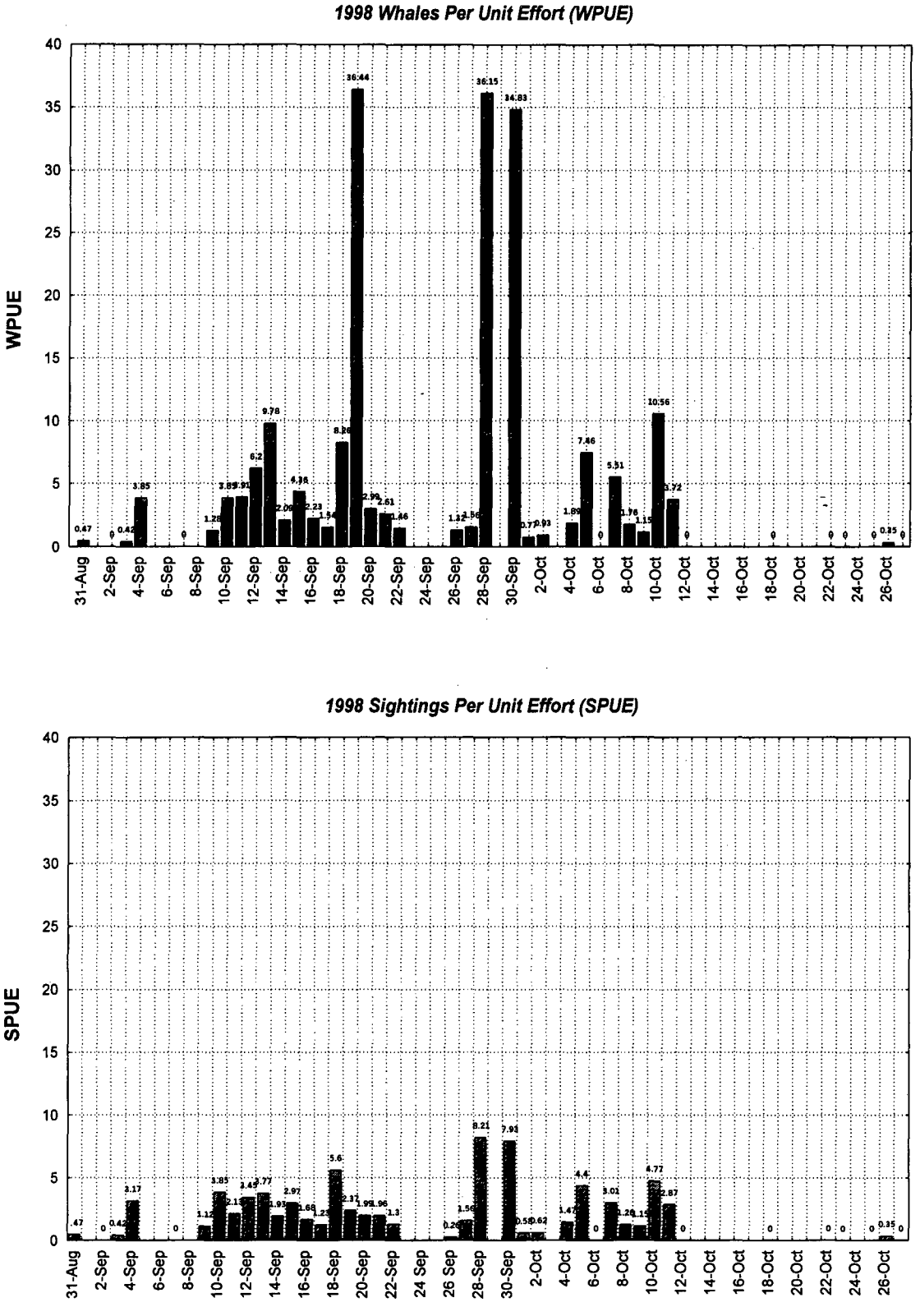

Figure 14. Daily Relative Abundance (WPUE) and Sighting Rate (SPUE) of Bowhead Whales, 31 August – 27 October 1998
(Zeros indicate days when flights were made but no whales were observed.)

The most prominent differences in pattern between the graph for relative abundance and that for sighting rate occurred on 19 September, 28 September, and 30 September (Fig. 14), due to several large pods of feeding whales observed on those days (Appendix C: Table C-1).

3. Habitat Associations: In addition to general ice coverage for arctic waters in 1998 (Appendix A), the percentage of ice cover visible from the aircraft at each bowhead sighting (Appendix C: Table C-1) was summarized. Over the field season, 1,044 whales (almost 100%) were sighted in open water (0% sea ice), with 1 whale (<1%) in 6- through 10-percent sea ice. Open water (0% sea ice) predominated throughout the field season (Table 5).

A description of water depth associated with the bowhead migration appears in the water-depth analyses in Section V.A.2.

4. Behaviors: Of 1,045 bowhead whales observed during Fall 1998, 433 (41%) were feeding, 418 (40%) swimming (moving forward in an apparently deliberate manner), and 98 (9%) milling when first sighted. Less frequent behaviors included 41 (4%) that were resting, 25 (2%) diving, 9 (1%) breaching, 8 (1%) tail-slapping, 6 (1%) thrashing, 4 (1%) in cow-calf associations, 1 log-playing, and 1 spy-hopping (Table 6). All behaviors noted are defined in Table 1.

Feeding bowhead whales were observed, mostly within 20 nm of shore, between 149°W. and 156°W. longitudes. The high percentage of feeding behaviors in Fall 1998 was likely associated with greater availability of prey species in this region. On 19 September, several large groups of bowhead whales were observed feeding near 71°10.0' N., between 154°31.0' W. and 155°21.8' W., further confirming the importance of the nearshore area east of Barrow as an occasional feeding area (Landino et al., 1994; Ljungblad et al., 1986) (Appendix C: Table C-1).

During the 1998 field season, there were no sightings of bowhead whales for which definite responses to the survey aircraft were apparent. Sudden overt changes (e.g., an abrupt dive, course diversion, or cessation of behavior ongoing) in whale behavior were looked for, but none were observed.

D. Other Marine Mammal Observations

1. Gray Whale (*Eschrichtius robustus*): Over the 1998 season, 3 incidental sightings were made for a total of 5 gray whales. The whales were sighted during September at 3 offshore locations between Deadhorse and Barrow (Table 3 and Fig. 15).

2. Beluga Whale (*Delphinapterus leucas*): Although the study area and survey altitude were designed to record the fall migration of bowhead whales, beluga whales, which undertake a somewhat parallel migration farther offshore, were always counted. Over the Fall 1998 field season, 26 sightings were made for a total of 306 beluga whales (Table 3) during 180.64 hr of survey effort (Table 2) and a seasonal relative abundance of 1.69 WPUE. Beluga whales were sighted beginning 3 September through 27 October, between 140°W. and 155°W. longitudes, mostly between 40 and 60 nm from shore, south of 72°N. latitude. A few pods near the Canadian border were closer to shore (Fig. 16). Sizes of pods (or close aggregations of pods) ranged from 1 to 75 whales, with a mean of 11.77 (SD=21.02, n=26). Forty-seven beluga calves were noted for a calf ratio of 0.15. All but one pod of belugas were sighted in open water (0% sea ice).

3. Bearded Seal (*Erignathus barbatus nauticus*): Over the 1998 season, 33 incidental sightings were made for a total of 38 bearded seals (Table 3 and Fig. 17). All but one of the bearded seals (observed on 27 October) were in open water (0% sea ice) when sighted.

4. Ringed Seal (*Pusa hispida hispida*): Over the 1998 season, 112 incidental sightings were made for a total of 938 ringed seals (Table 3). Sightings were made across the study area, mostly between 0 and 70 nm from shore (Fig. 18). All the ringed seals observed before 9 October were in open water (0% sea ice).

Table 5
Semimonthly Summary of Bowhead Whales Observed,
by Percent Ice Cover Present at Sighting Location, Fall 1998

% Ice Cover	31 Aug	1-15 Sep	16-30 Sep	1-15 Oct	16-27 Oct	Total
0	1 (100%)	173 (100%)	707 (100%)	162 (100%)	1 (50%)	1,044 (100%)
1-5	0	0	0	0	0	0
6-10	0	0	0	0	1 (50%)	1
11-20	0	0	0	0	0	0
21-30	0	0	0	0	0	0
31-40	0	0	0	0	0	0
41-50	0	0	0	0	0	0
51-60	0	0	0	0	0	0
61-70	0	0	0	0	0	0
71-80	0	0	0	0	0	0
81-90	0	0	0	0	0	0
91-99	0	0	0	0	0	0
TOTAL	1 (100%)	173 (100%)	707 (100%)	162 (100%)	2 (100%)	1,045 (100%)

Table 6
Semimonthly Summary of Bowhead Whales Observed, by Behavioral Category, Fall 1998

Behavior	31 Aug	1-15 Sep	16-30 Sep	1-15 Oct	16-27 Oct	Total
Breaching	0	5 (3%)	4 (1%)	0	0	9 (1%)
Cow-Calf	0	0	4 (1%)	0	0	4 (1%)
Diving	0	10 (6%)	12 (2%)	3 (2%)	0	25 (2%)
Feeding	0	6 (3%)	406 (57%)	21 (13%)	0	433 (41%)
Log Playing	0	1 (1%)	0	0	0	1
Milling	0	26 (15%)	55 (8%)	17 (10%)	0	98 (9%)
Resting	0	10 (6%)	24 (3%)	6 (4%)	1 (50%)	41 (4%)
Spy Hopping	0	0	0	1 (1%)	0	1
Swimming	1 (100%)	109 (63%)	194 (27%)	113 (70%)	1 (50%)	418 (40%)
Tail Slapping	0	6 (3%)	1	1 (1%)	0	8 (1%)
Thrashing	0	0	6 (1%)	0	0	6 (1%)
(not noted)	0	0	1	0	0	1
TOTAL	1 (100%)	173 (100%)	707 (100%)	162 (100%)	2 (100%)	1,045 (100%)

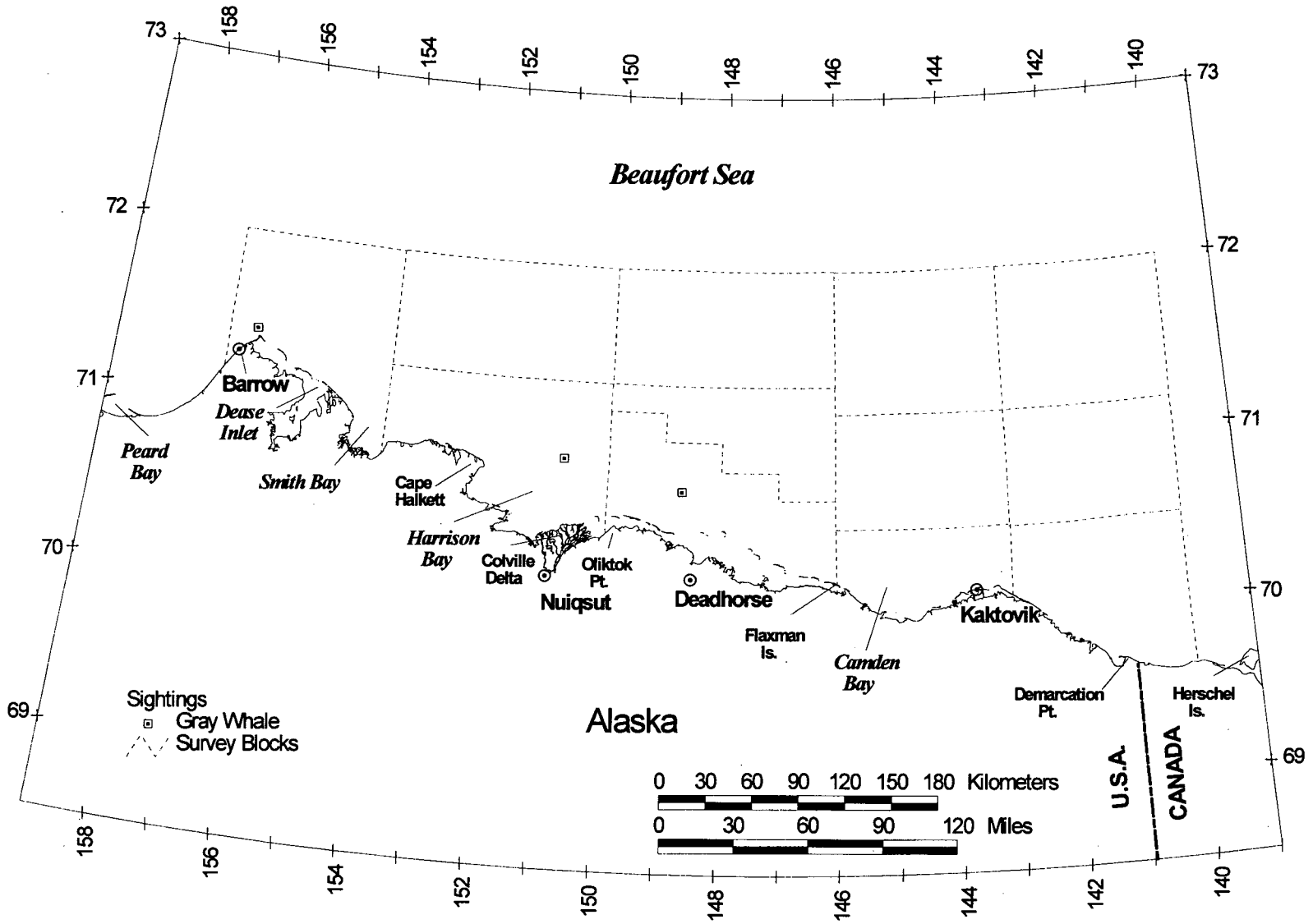

Figure 15. Map of Gray Whale Sightings, Fall 1998

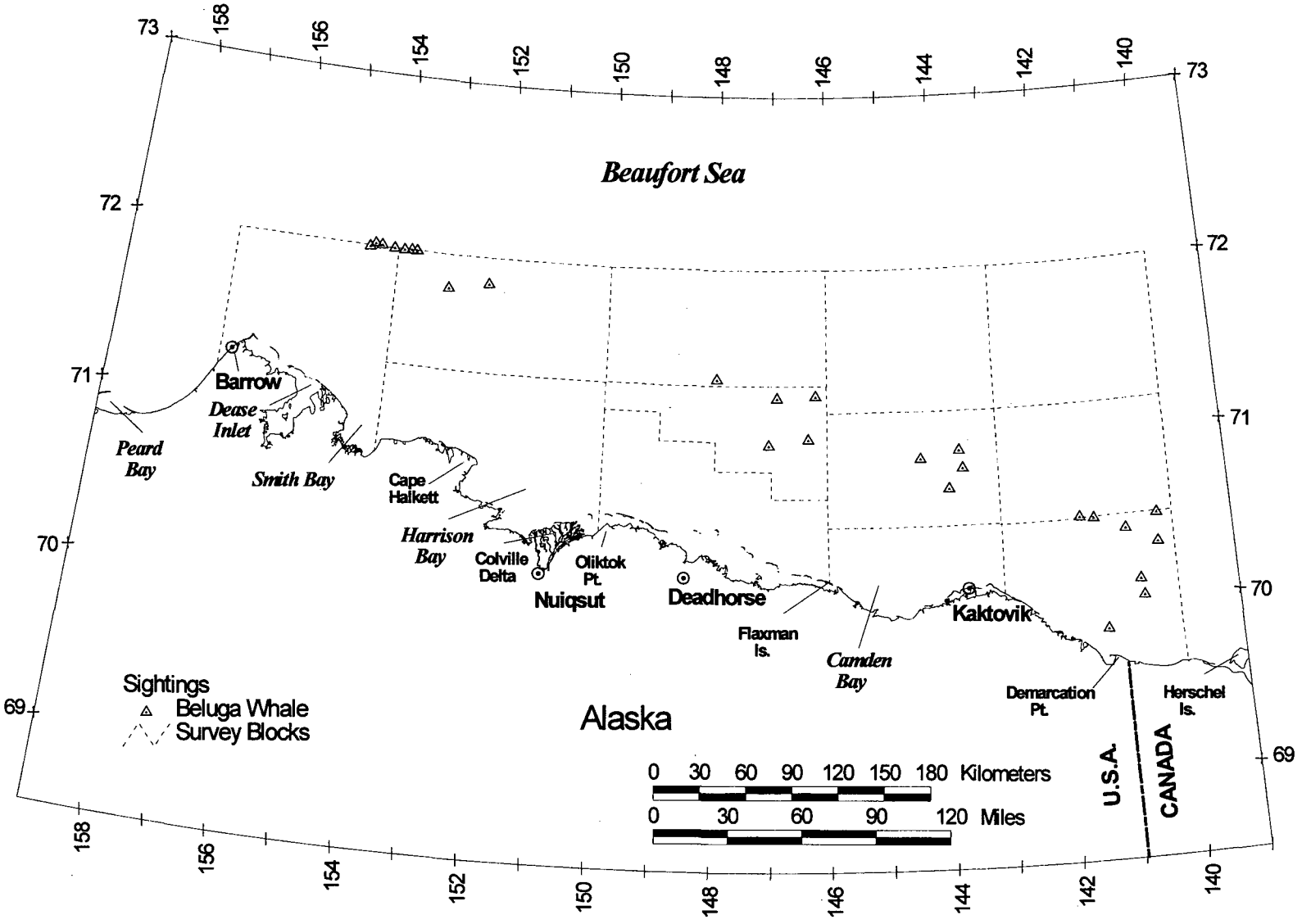

Figure 16. Map of Beluga Whale Sightings, Fall 1998

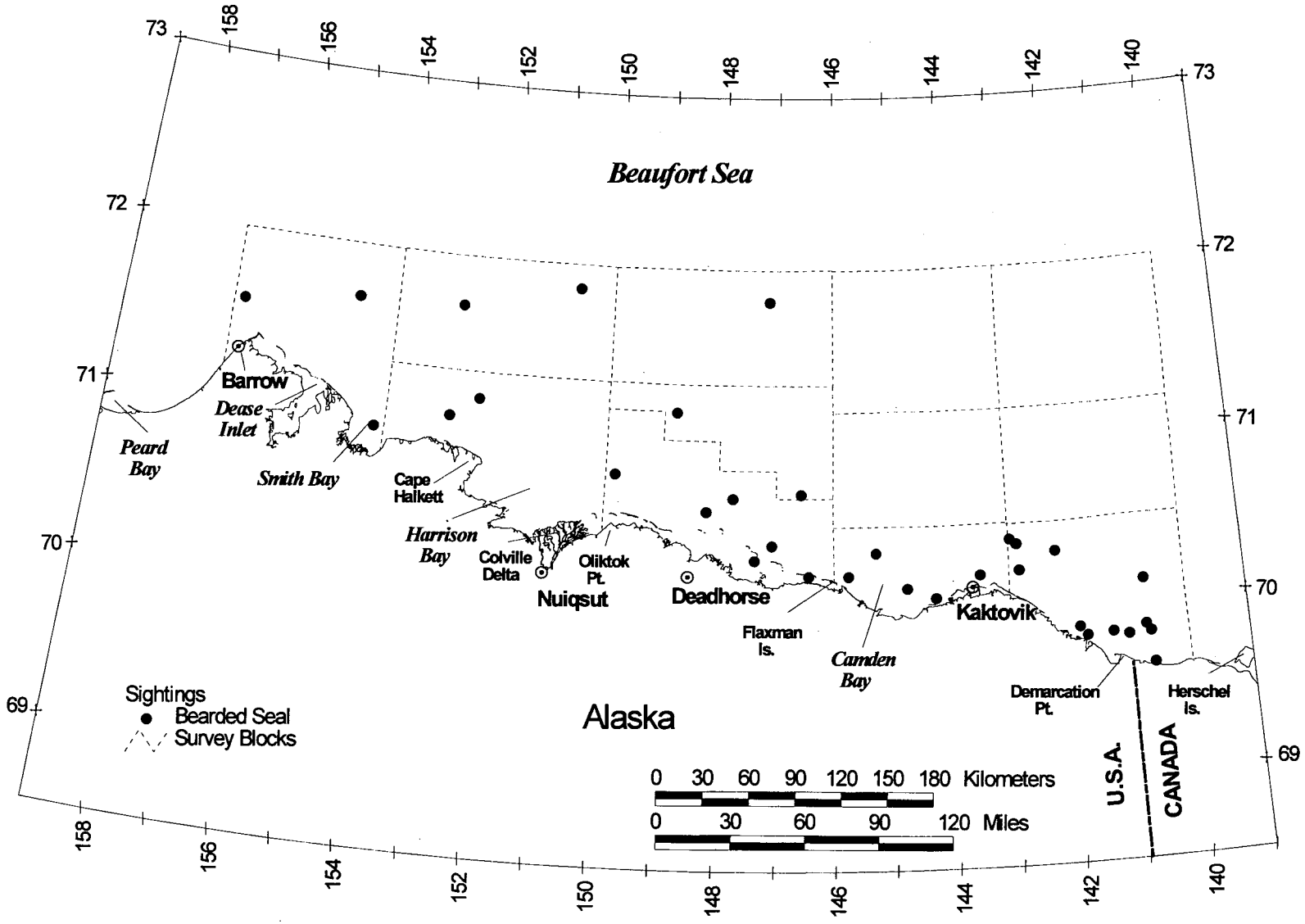

Figure 17. Map of Bearded Seal Sightings, Fall 1998

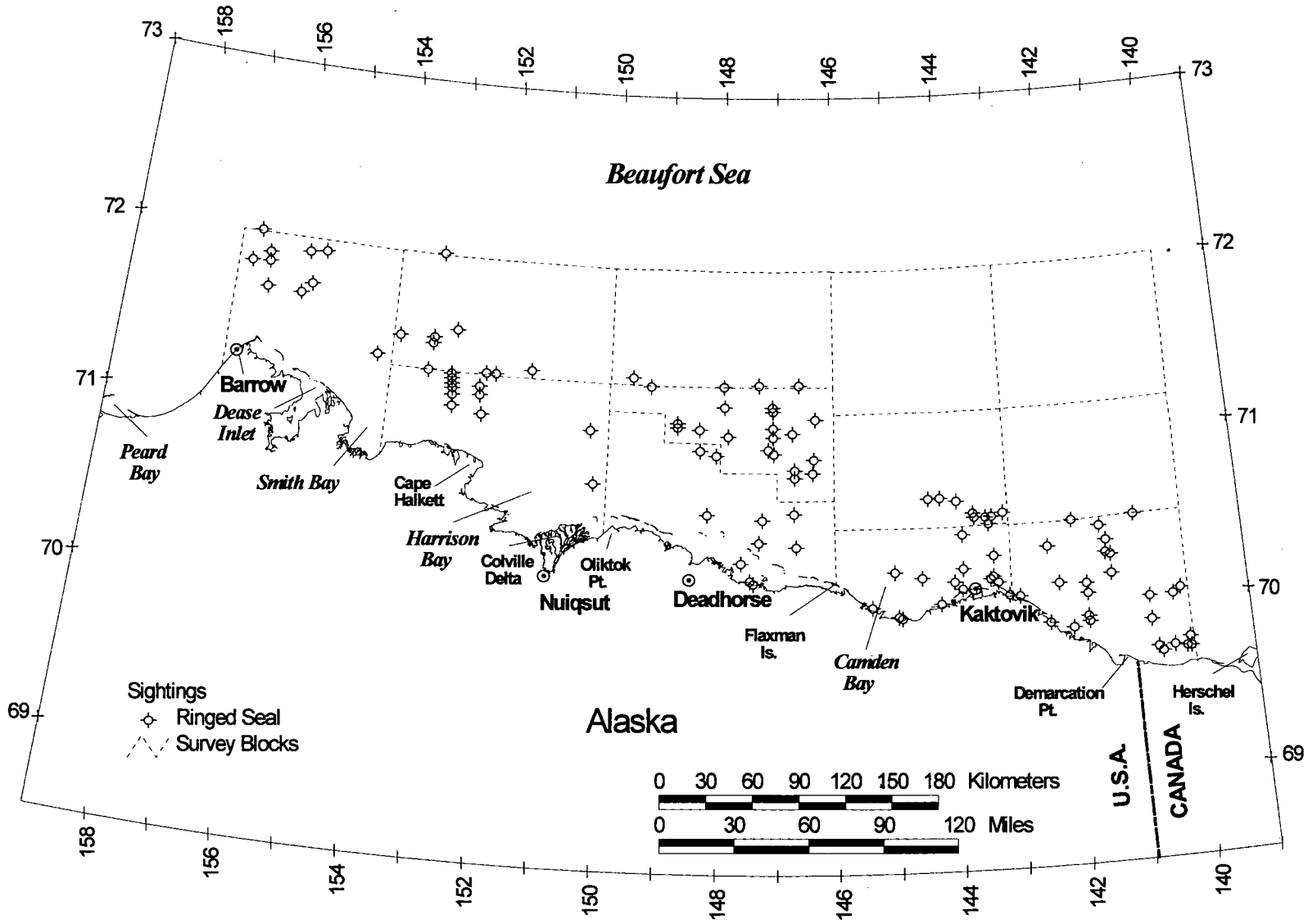

Figure 18. Map of Ringed Seal Sightings, Fall 1998

5. Walrus (*Odobenus rosmarus divergens*): Over the 1998 season, 3 incidental sightings were made for a total of 3 walruses. Two sightings near the Canadian border included one on 1 October as far east as 141°25.7' W. longitude (Table 3 and Fig. 19).

6. Unidentified Cetaceans and Pinnipeds: Over the 1998 season, there were 10 incidental sightings for a total of 20 unidentified pinnipeds and no sightings of unidentified cetaceans (Table 3).

7. Polar Bear (*Ursus maritimus marinus*): Over the 1998 season, 69 incidental sightings were made for a total of 235 polar bears (Table 3). Most of the bears were on barrier islands between 142°W. and 150°W. longitudes (Fig. 20). An unknown proportion of these bears appeared to remain on the islands waiting for the sea ice and may have been recounted on subsequent days. In addition to the polar bear sightings, 26 sets of polar bear tracks were noted for which no bear was present. Tracks mirrored the distribution of observed bears, with some inshore tracks extending farther east to Demarcation Point (Table 3 and Fig. 21).

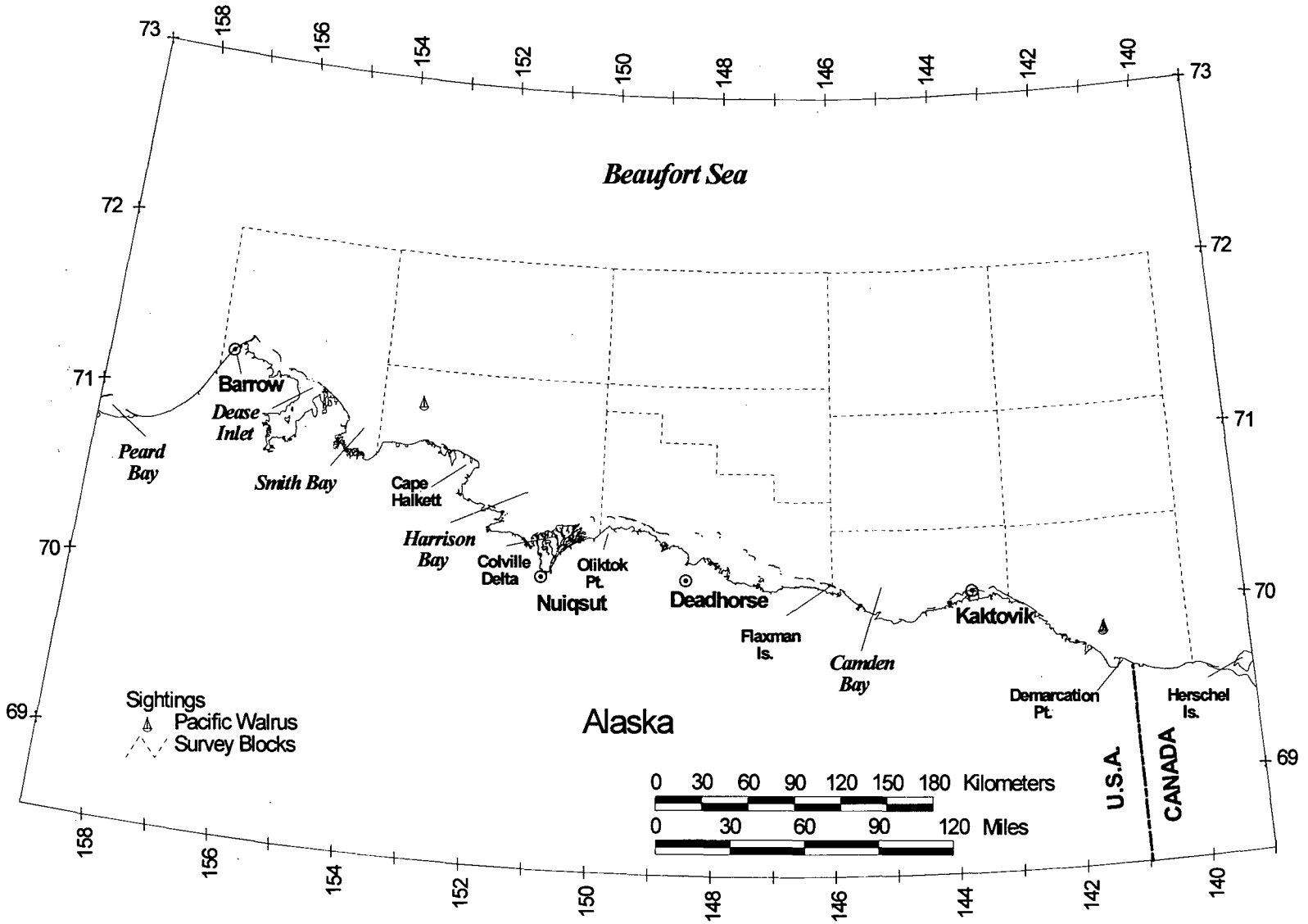

Figure 19. Map of Pacific Walrus Sightings, Fall 1998

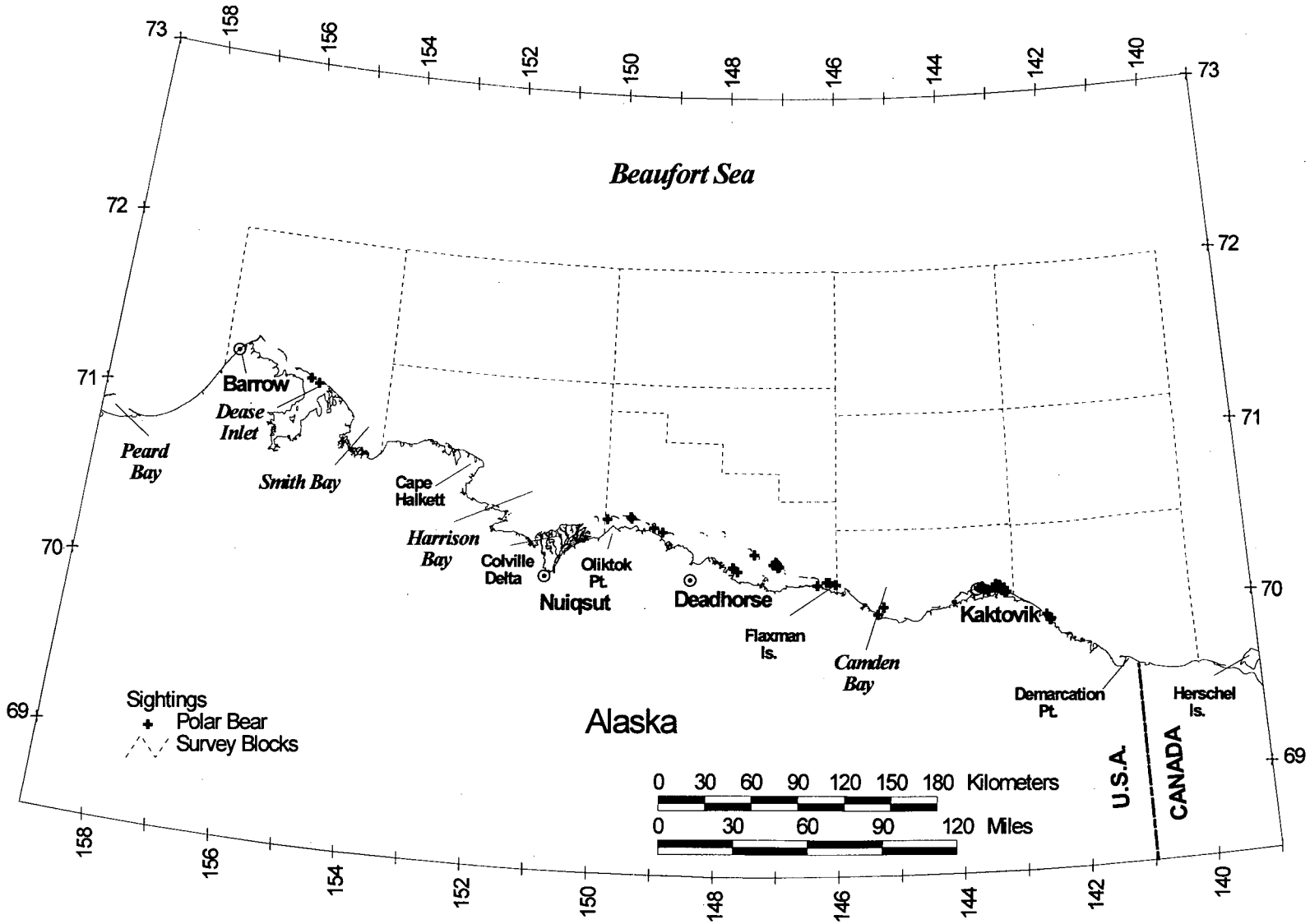

Figure 20. Map of Polar Bear Sightings, Fall 1998

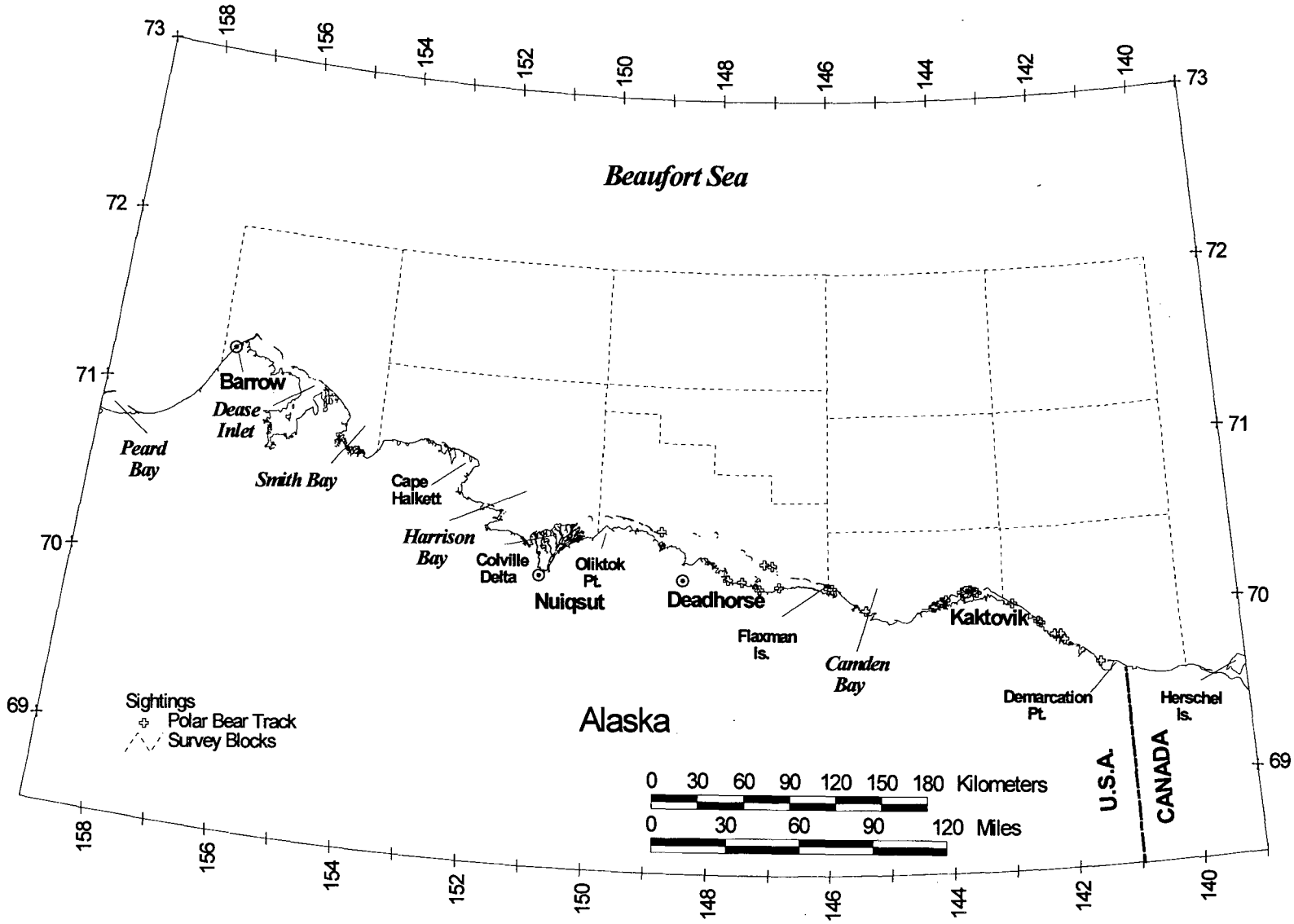

Figure 21. Map of Polar Bear Tracks, Fall 1998

IV. FALL 1999 RESULTS

A. Environmental Conditions

General ice coverage during Fall 1999 in the Alaskan Beaufort Sea (Appendix B) was light during the month of September. From 27 August through 24 September, conditions were generally ice-free south of 72° N. latitude, with the exception of some localized medium concentrations (20-79%) in the northeastern part of the study area. By 1 October, 20- through 39-percent sea ice had formed along much of the shoreline. By 8 October, the shore-fast ice was in an unbroken strip of 60- through 79-percent concentration from Barrow to Kaktovik. By 15 October, light to moderate offshore ice concentrations prevailed over much of the study area east of 152°W. longitude. By 22 October, near-solid ice (>94%) covered all but the westernmost part of the study area. By 29 October, the entire study area was blanketed in almost near-solid ice. Ice percent at each sighting of endangered whales is shown in Appendix D.

Environmental conditions permitted 36 flights during Fall 1999. The weather was notably poor (high sea states and/or low cloud ceilings) from 18 through 23 September and from 2 through 12 October, permitting no survey hours in those time periods (Table 7).

B. Survey Effort

Daily totals of kilometers and hours flown per survey flight during Fall 1999 are shown in Table 7. A total of 26,053 km of surveys were flown in 114.16 hours in the study area at an average speed of 228.21 km/hr. The average survey flight was 723.69 km, with over-ocean flight distances ranging from 10 km to 1,455 km. A total of 13,511 km of random-transect lines were flown in 60.15 hours at an average speed of 224.62 km/hr. These random transects constituted 51.86 percent of the total kilometers flown and 52.69 percent of the total flight hours. Survey-flight lines are summarized by semimonthly period in Figures 22 through 26.

On 31 August, survey coverage ranged from 146°W. to 148°W. longitudes, within 40 nautical miles (nm) of shore (Fig. 22). There were 0.88 hours of random transects flown out of 1.65 total flight hours during this period (Table 7), constituting 1.5 percent and 1.4 percent, respectively, of the total time spent in those effort categories.

During the first half of September, survey coverage ranged from 140°W. to 154°W. longitudes, within 90 nm of shore (Fig. 23). There were 19.07 hours of random transects flown out of 39.01 total flight hours during this period (Table 7), constituting 31.7 percent and 34.2 percent, respectively, of the total time spent in those effort categories.

During the second half of September, survey coverage ranged from 140°W. to 157°W. longitudes, within 100 nm of shore (Fig. 24). There were 12.73 hours of random transects flown out of 25.48 total flight hours during this period (Table 7), constituting 21.2 percent and 22.3 percent, respectively, of the total time spent in those effort categories.

During the first half of October, survey coverage ranged from 146°W. to 157°W. longitudes, within 70 nm of shore (Fig. 25). There were 9.15 hours of random transects flown out of 15.75 total flight hours during this period (Table 7), constituting 15.2 percent and 13.8 percent, respectively, of the total time spent in those effort categories. Poor weather conditions limited survey coverage during this period.

From 16 through 23 October, survey coverage ranged from 146°W. to 157°W. longitudes, within 90 nm of shore (Fig. 26). There were 18.32 hours of random transects flown out of 32.27 total flight hours during this period (Table 7), constituting 30.5 percent and 28.3 percent, respectively, of the total time spent in those effort categories.

Table 7
Aerial-Survey Effort in the Beaufort Sea, 31 August-23 October 1999, by Survey Flight

Day	Flight No.	Transect (km)	Connect (km)	Search (km)	Total (km)	Transect (hr)	Total (hr)
31 Aug	1	180	49	91	320	0.88	1.65
2 Sep	2	0	0	65	65	0.00	0.23
3 Sep	3	0	0	174	174	0.00	0.83
3 Sep	4	259	81	281	621	1.12	2.63
5 Sep	5	0	0	10	10	0.00	0.03
6 Sep	6	970	206	258	1,434	4.38	6.47
7 Sep	7	828	203	411	1,441	3.68	6.42
8 Sep	8	11	0	182	192	0.05	0.75
9 Sep	9	557	98	262	918	2.45	4.02
10 Sep	10	0	0	115	115	0.00	0.55
10 Sep	11	75	0	474	549	0.33	2.43
11 Sep	12	699	214	453	1,366	3.05	6.15
12 Sep	13	361	44	545	950	1.58	3.87
13 Sep	14	553	191	367	1,111	2.43	4.63
16 Sep	15	0	0	199	199	0.00	0.73
16 Sep	16	406	179	463	1,048	1.75	4.45
17 Sep	17	643	212	236	1,091	2.77	4.72
20 Sep	18	0	0	227	227	0.00	0.97
24 Sep	19	397	46	493	936	1.68	4.03
25 Sep	20	459	121	367	947	2.05	4.20
29 Sep	21	1,007	115	216	1,338	4.48	6.10
30 Sep	22	0	0	60	60	0.00	0.28
1 Oct	23	0	0	136	136	0.00	0.63
11 Oct	24	38	0	166	204	0.15	0.77
13 Oct	25	555	102	584	1,241	2.47	5.17
14 Oct	26	396	59	14	470	1.78	2.17
14 Oct	27	511	69	71	651	2.37	3.07
15 Oct	28	245	54	79	377	1.10	1.67
15 Oct	29	289	55	108	452	1.28	2.27
17 Oct	30	1,012	158	285	1,455	4.47	6.33
18 Oct	31	703	134	578	1,415	3.15	6.07
20 Oct	32	208	24	149	381	0.95	1.72
20 Oct	33	464	173	86	722	2.05	3.23
21 Oct	34	817	108	487	1,411	3.73	6.28
22 Oct	35	855	138	418	1,410	3.92	6.27
23 Oct	36	13	0	603	616	0.05	2.37
Semimonthly Effort Summary							
31 Aug		180	49	91	320	0.88	1.65
1-15 Sep		4,313	1,037	3,597	8,946	19.07	39.01
16-30 Sep		2,912	673	2,261	5,846	12.73	25.48
1-15 Oct		2,034	339	1,158	3,531	9.15	15.75
16-23 Oct		4,072	735	2,606	7,410	18.32	32.27
TOTAL		13,511	2,833	9,713	26,053	60.15	114.16

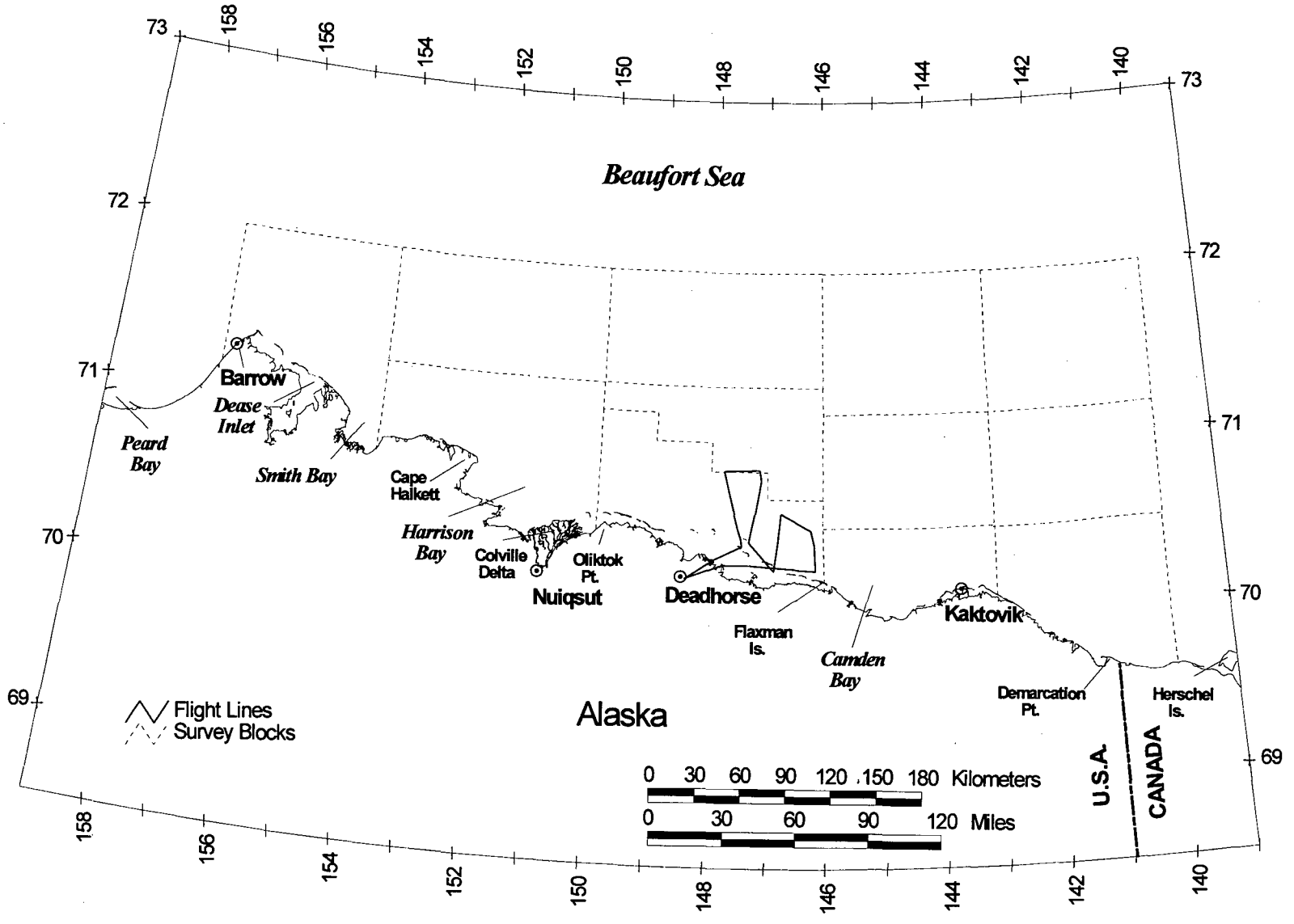

Figure 22. Flight Track, 31 August 1999

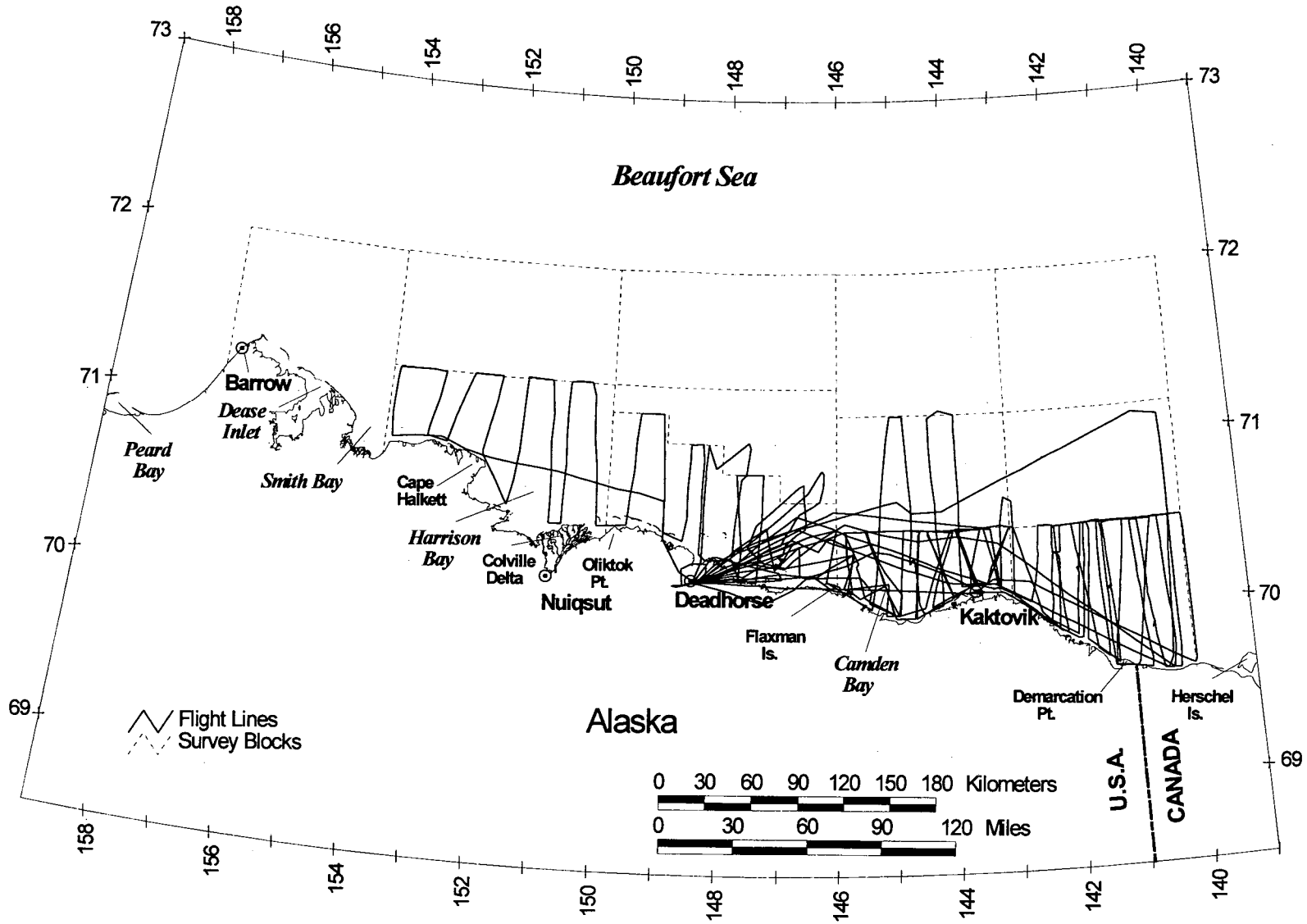

Figure 23. Combined Flight Tracks, 1-15 September 1999

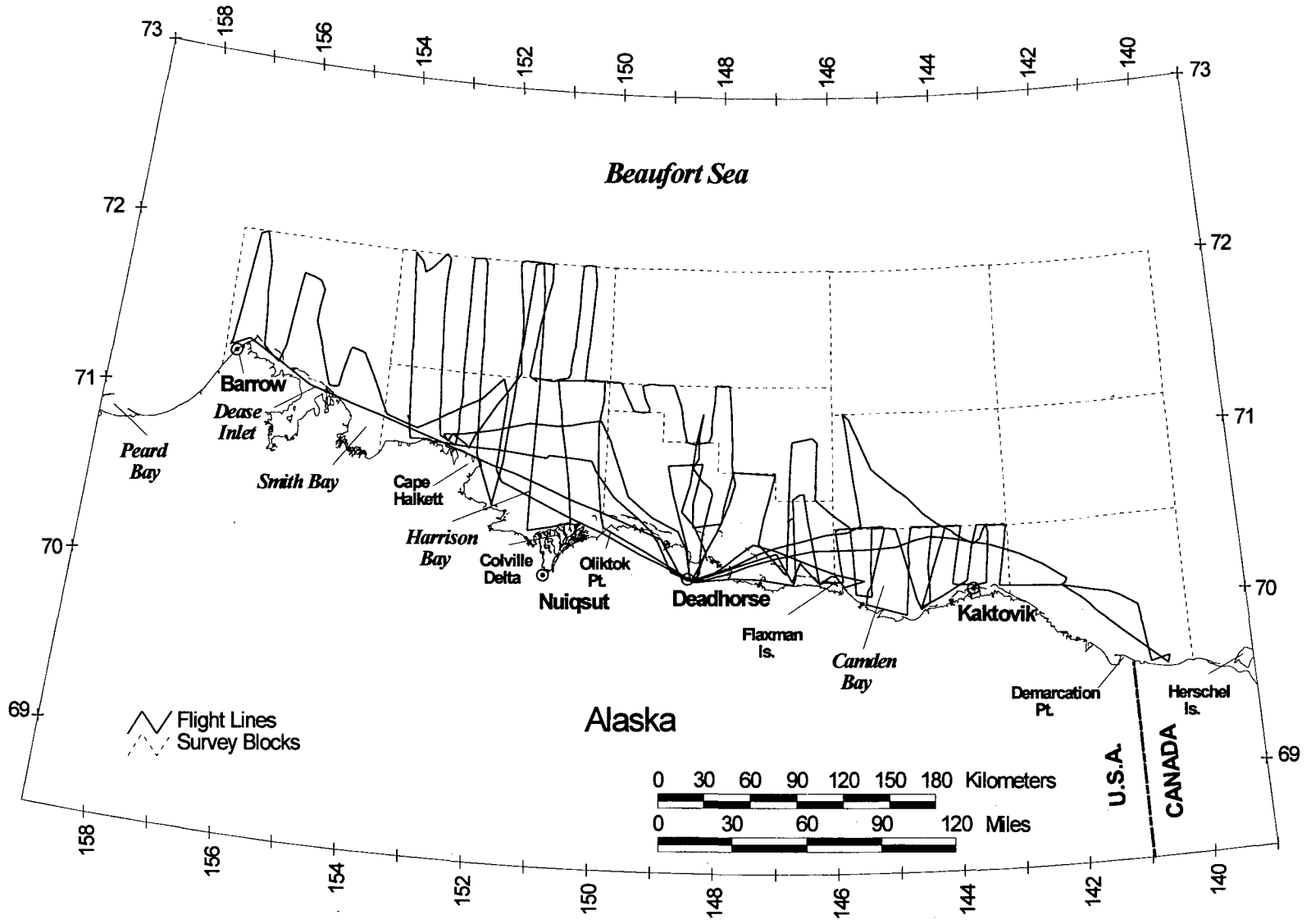

Figure 24. Combined Flight Tracks, 16-30 September 1999

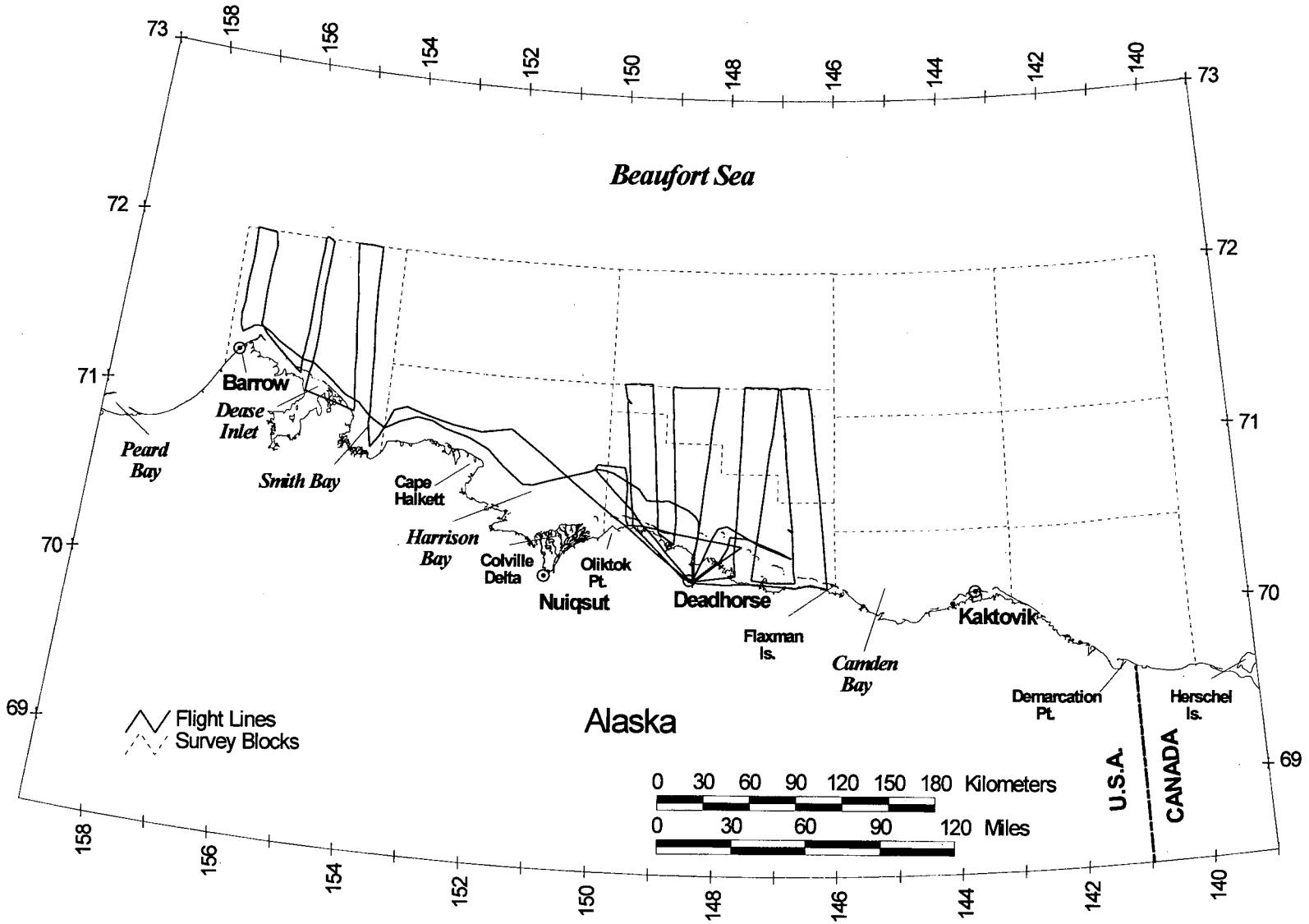

Figure 25. Combined Flight Tracks, 1-15 October 1999

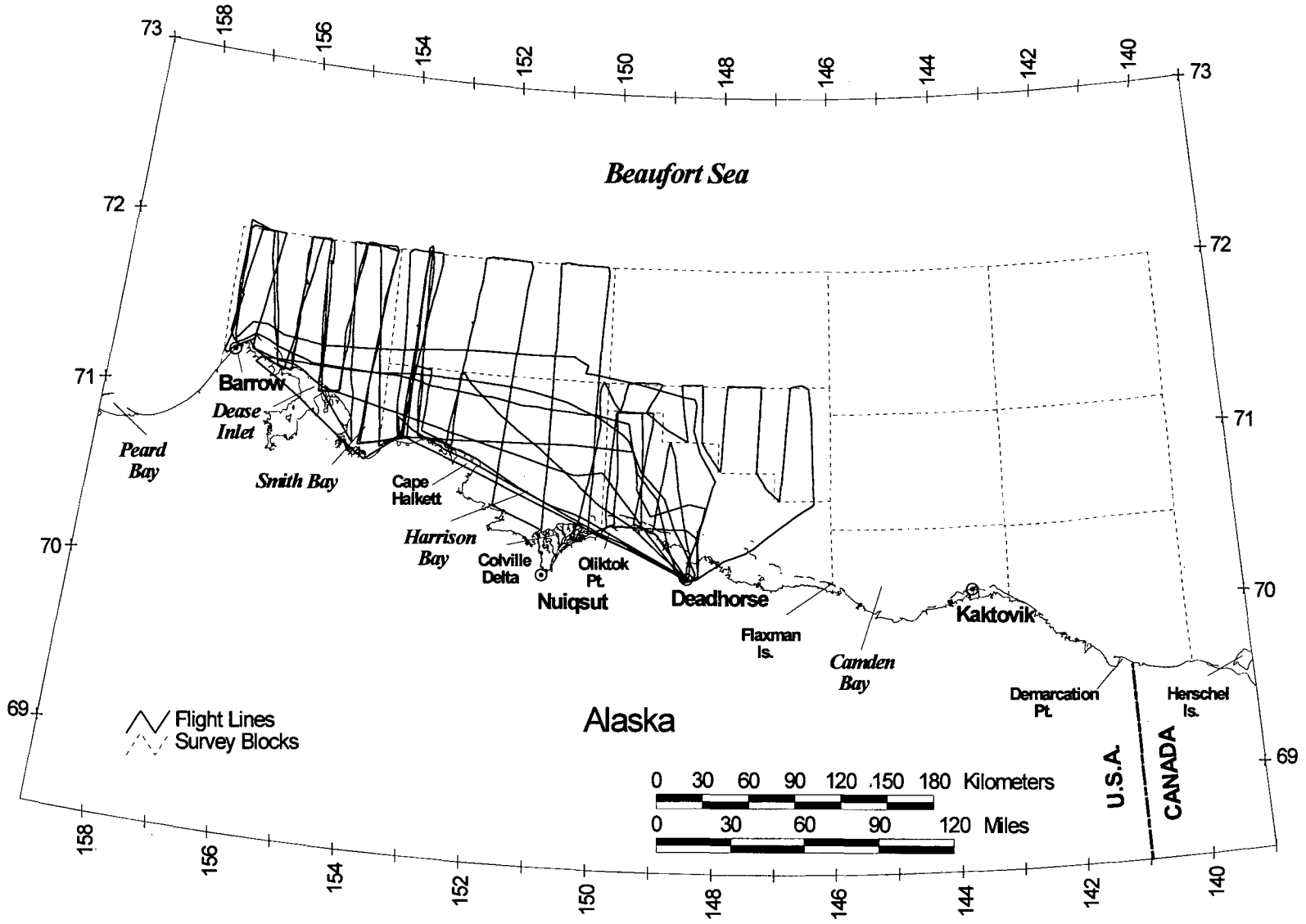

Figure 26. Combined Flight Tracks, 16-23 October 1999

C. Bowhead Whale (*Balaena mysticetus*) Observations

1. Distribution: Two hundred fourteen sightings were made for a total of 397 bowhead whales observed during Fall-1999 surveys in the study area (Table 8 and Figs. 27-31), not counting definite repeat sightings or dead whales. Total survey coverage between 140°W. and 157°W. longitudes (Figs. 23-26), resulted in distribution of bowhead whales all across the study area generally within 50 nm north of the shoreline, with heavier concentrations (unadjusted for effort) between 140°W. and 145°W. and between 151°W. and 157°W. longitudes (Fig. 31). Nine of the 397 whales were identified as calves (Appendix D: Table D-1), resulting in a seasonal calf ratio (number calves/total whales) of 0.023. A semi-monthly analysis follows.

There were no bowhead whales observed on 31 August (Table 8).

During the first half of September, 70 sightings were made for a total of 96 bowheads (Table 8), with sightings between 140°W. and 152°W. longitudes, based on survey coverage between 140°W. and 154°W. longitudes (Fig. 23). The first bowhead in the Alaskan Beaufort Sea was sighted at 70°14.8′N. latitude, 144°00.0′W. longitude. Whale pods were concentrated between 140°W. and 145°W. longitudes, within 40 nm north of the shoreline (Fig. 27). Pod sizes ranged from 1 to 5 whales, with a mean of 1.37 (SD=0.71, n=70). Four bowhead whale calves were observed during this period (Appendix D: Table D-1).

During the second half of September, 55 sightings were made for a total of 78 bowheads (Table 8), with sightings from 140°W. to 157°W. longitudes, based on survey coverage between 140°W. and 157°W. longitudes (Fig. 24). Whale pods were distributed fairly evenly east to west across the study area, within 40 nm north of the shoreline (Fig. 28). Pod sizes ranged from 1 to 4 whales, with a mean of 1.42 (SD=0.83, n=55). No bowhead whale calves were observed during this period (Appendix D: Table D-1).

During the first half of October, 15 sightings were made for a total of 18 bowheads (Table 8), with sightings from 146°W. to 157°W. longitudes, based on survey coverage between 146°W. and 157°W. longitudes (Fig. 25). Whale pods were distributed evenly in those areas where transect effort was made, with most pods in Survey Block 1, mostly within 30 nm north of the shoreline (Fig. 29). Pod sizes ranged from 1 to 3 whales, with a mean of 1.20 (SD=0.56, n=15). No bowhead whale calves were observed during this period (Appendix D: Table D-1).

From 16 through 23 October, 74 sightings were made for a total of 205 bowheads (Table 8), with sightings from 148°W. to 157°W. longitudes, based on survey coverage between 146°W. and 157°W. longitudes (Fig. 26). Whale pods were mostly located in a tight pattern offshore between Barrow and Oliktok Point, mostly between 10 and 40 nm north of the shoreline (Fig. 30). This tight pattern, while reflecting survey effort to an extent, fit neatly with the ice-free area shown for 15 and 22 October (Appendix B). Pod sizes ranged from 1 to 50 whales, with a mean of 2.77 (SD=7.05, n=74). The last bowhead in the Alaskan Beaufort Sea was sighted at 71°06.6′N. latitude, 153°35.0′W. longitude. Five bowhead whale calves were observed during this period (Appendix D: Table D-1).

2. Migration Timing and Relative Abundance: The day-to-day timing of the bowhead whale migration during Fall 1999 was calculated over the entire study area (Table 9 and Fig. 32).

Of the 214 sightings of bowhead whale pods, the first whales observed were on 3 September. The data for daily sighting rates showed a fairly level distribution over the field season, with higher values on 11 September (4.39 SPUE), 16 September (4.49 SPUE), and 21 October (4.46 SPUE). The low values in Figure 32 for 18-23 September and 2-12 October were due to poor flying weather. The last sighting of a bowhead whale was made on 22 October (Table 9 and Fig. 32).

Of the 397 individual bowhead whales counted, the data for daily relative abundance show that the midpoint (median) of the bowhead migration in Blocks 1 through 12 (when 50% of all sighted whales had been

Table 8
Summary of Marine Mammal Sightings, 31 August-23 October 1999, by Survey Flight
(number of sightings/number of animals)

Day	Flight No.	Bowhead Whale	Gray Whale	Beluga Whale	Unidentified Cetacean	Bearded Seal	Ringed Seal	Pacific Walrus	Unidentified Pinniped	Polar Bear (PB)	PB Tracks (no bear)
31 Aug	1	0	0	0	0	0	0	0	0	1/1	0
2 Sep	2	0	0	0	0	0	0	0	0	0	0
3 Sep	3	0	0	0	0	1/1	0	0	0	1/1	0
3 Sep	4	10/13	0	1/1	0	7/8	10/20	0	0	1/1	0
5 Sep	5	0	0	0	0	0	0	0	0	0	0
6 Sep	6	2/2	0	4/22	0	0	0	0	1/1	0	0
7 Sep	7	17/30	0	2/3	0	15/19	43/336	0	2/3	3/8	1
8 Sep	8	0	0	0	0	0	1/2	0	0	0	0
9 Sep	9	2/3	0	0	0	0	0	0	1/1	1/1	0
10 Sep	10	0	0	0	0	0	0	0	0	2/2	0
10 Sep	11	1/1	0	0	0	0	6/34	0	0	0	0
11 Sep	12	27/33	0	6/21	1/1	9/9	28/116	0	0	4/4	0
12 Sep	13	3/4	0	3/20	0	1/1	20/67	0	0	4/13	0
13 Sep	14	8/10	0	1/2	0	5/6	8/25	0	0	2/2	0
16 Sep	15	0	0	0	0	0	0	0	0	0	0
16 Sep	16	20/28	0	1/1	0	3/3	21/46	0	0	1/1	0
17 Sep	17	9/13	0	4/113	0	13/19	36/275	0	1/1	0	1
20 Sep	18	0	0	0	0	1/1	0	0	0	0	0
24 Sep	19	10/14	1/2	0	0	0	0	0	0	0	0
25 Sep	20	2/2	0	0	0	0	42/207	0	0	0	0
29 Sep	21	14/21	0	8/50	0	3/3	34/181	0	0	1/1	0
30 Sep	22	0	0	0	0	0	0	0	0	0	0
1 Oct	23	1/1	0	0	0	0	0	0	0	0	0
11 Oct	24	0	0	0	0	0	0	0	0	0	1
13 Oct	25	6/7	0	5/15	0	1/1	2/3	0	0	0	0
14 Oct	26	4/6	0	7/25	0	0	0	0	0	0	0
14 Oct	27	3/3	0	0	0	2/2	2/9	0	0	0	0
15 Oct	28	1/1	0	0	0	1/1	0	0	0	0	0

Table 8
Summary of Marine Mammal Sightings, 31 August-23 October 1999, by Survey Flight
(number of sightings/number of animals)

Day	Flight No.	Bowhead Whale	Gray Whale	Beluga Whale	Unidentified Cetacean	Bearded Seal	Ringed Seal	Pacific Walrus	Unidentified Pinniped	Polar Bear (PB)	PB Tracks (no bear)
15 Oct	29	0	0	0	0	0	0	0	0	0	10
17 Oct	30	11/16	0	16/71	0	2/2	1/1	0	0	0	3
18 Oct	31	23/117	0	3/16	0	0	3/3	0	0	0	1
20 Oct	32	1/1	0	0	0	0	0	0	0	1/1	5
20 Oct	33	0	0	4/27	0	0	1/1	0	1/1	0	22
21 Oct	34	28/54	0	8/17	0	1/1	1/1	0	2/2	1/1	12
22 Oct	35	11/17	0	13/42	0	4/4	0	0	1/1	0	9
23 Oct	36	0	0	0	0	0	0	0	0	0	5
31 Aug		0	0	0	0	0	0	0	0	1/1	0
1-15 Sep		70/96	0	17/69	1/1	38/44	116/598	0	4/5	18/32	1
16-30 Sep		55/78	1/2	13/164	0	20/26	133/709	0	1/1	2/2	1
1-15 Oct		15/18	0	12/40	0	4/4	4/12	0	0	0	11
16-23 Oct		74/205	0	44/173	0	7/7	6/6	0	4/4	2/2	57
TOTAL		214/397	1/2	86/446	1/1	69/81	259/1,325	0	9/10	23/37	70

Table 9
Number of Sightings and Total Bowhead Whales Observed per Hour,
31 August-23 October 1999, by Flight Day

Day	No. of Sightings	No. of Whales	Survey Time (hr)	Sightings/hr (SPUE)	Whales/hr (WPUE)
31 Aug	0	0	1.65	0.00	0.00
2 Sep	0	0	0.23	0.00	0.00
3 Sep	10	13	3.46	3.80	4.94
5 Sep	0	0	0.03	0.00	0.00
6 Sep	2	2	6.47	0.31	0.31
7 Sep	17	30	6.42	2.65	4.67
8 Sep	0	0	0.75	0.00	0.00
9 Sep	2	3	4.02	0.50	0.75
10 Sep	1	1	2.98	0.41	0.41
11 Sep	27	33	6.15	4.39	5.37
12 Sep	3	4	3.87	0.78	1.03
13 Sep	8	10	4.63	1.73	2.16
16 Sep	20	28	5.18	4.49	6.29
17 Sep	9	13	4.72	1.91	2.75
20 Sep	0	0	0.97	0.00	0.00
24 Sep	10	14	4.03	2.48	3.47
25 Sep	2	2	4.20	0.48	0.48
29 Sep	14	21	6.10	2.30	3.44
30 Sep	0	0	0.28	0.00	0.00
1 Oct	1	1	0.63	1.59	1.59
11 Oct	0	0	0.77	0.00	0.00
13 Oct	6	7	5.17	1.16	1.35
14 Oct	7	9	5.24	2.82	3.74
15 Oct	1	1	3.94	0.60	0.60
17 Oct	11	16	6.33	1.74	2.53
18 Oct	23	117	6.07	3.79	19.28
20 Oct	1	1	4.95	0.58	0.58
21 Oct	28	54	6.28	4.46	8.60
22 Oct	11	17	6.27	1.75	2.71
23 Oct	0	0	2.37	0.00	0.00

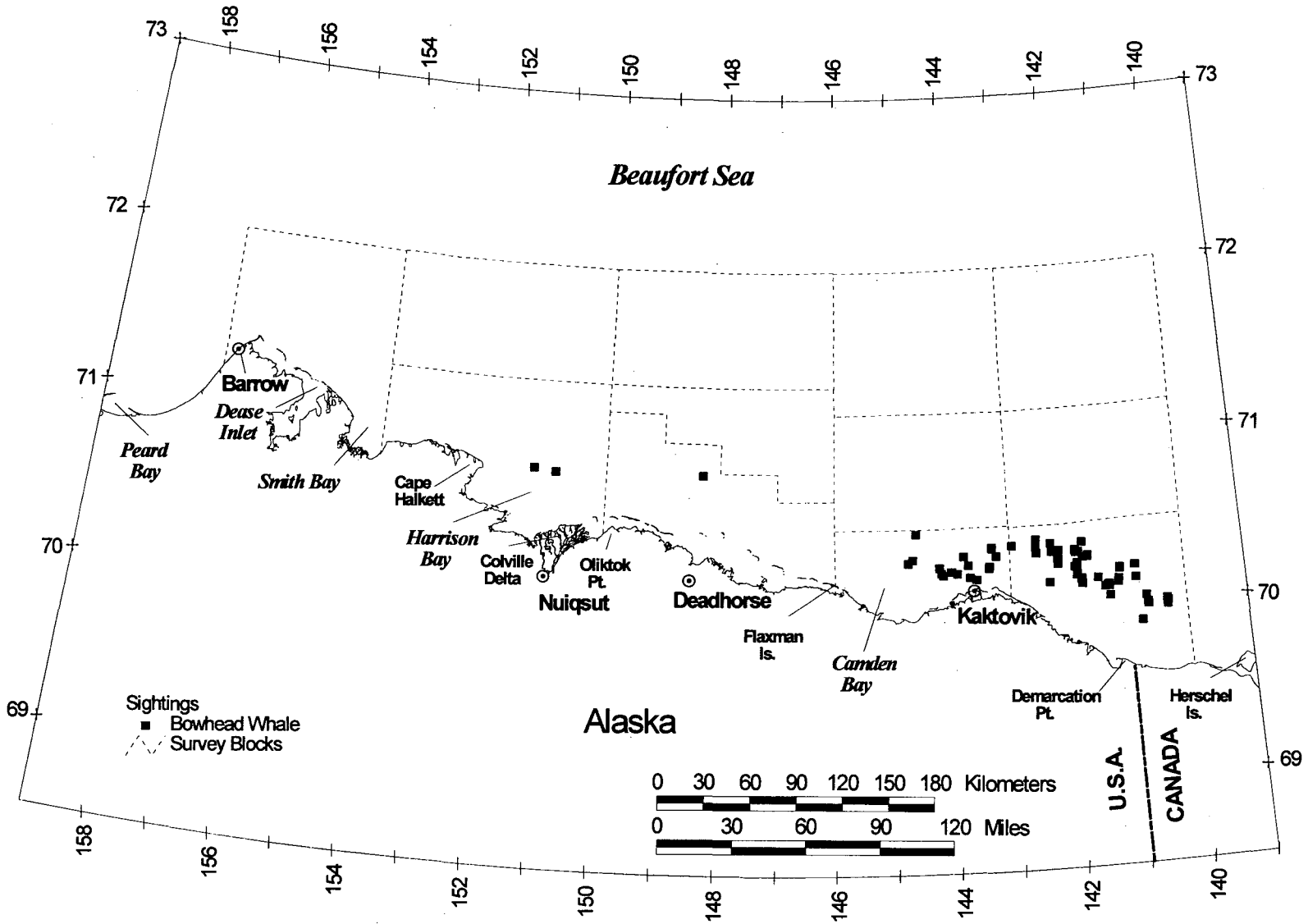

Figure 27. Map of Bowhead Whale Sightings, 1-15 September 1999

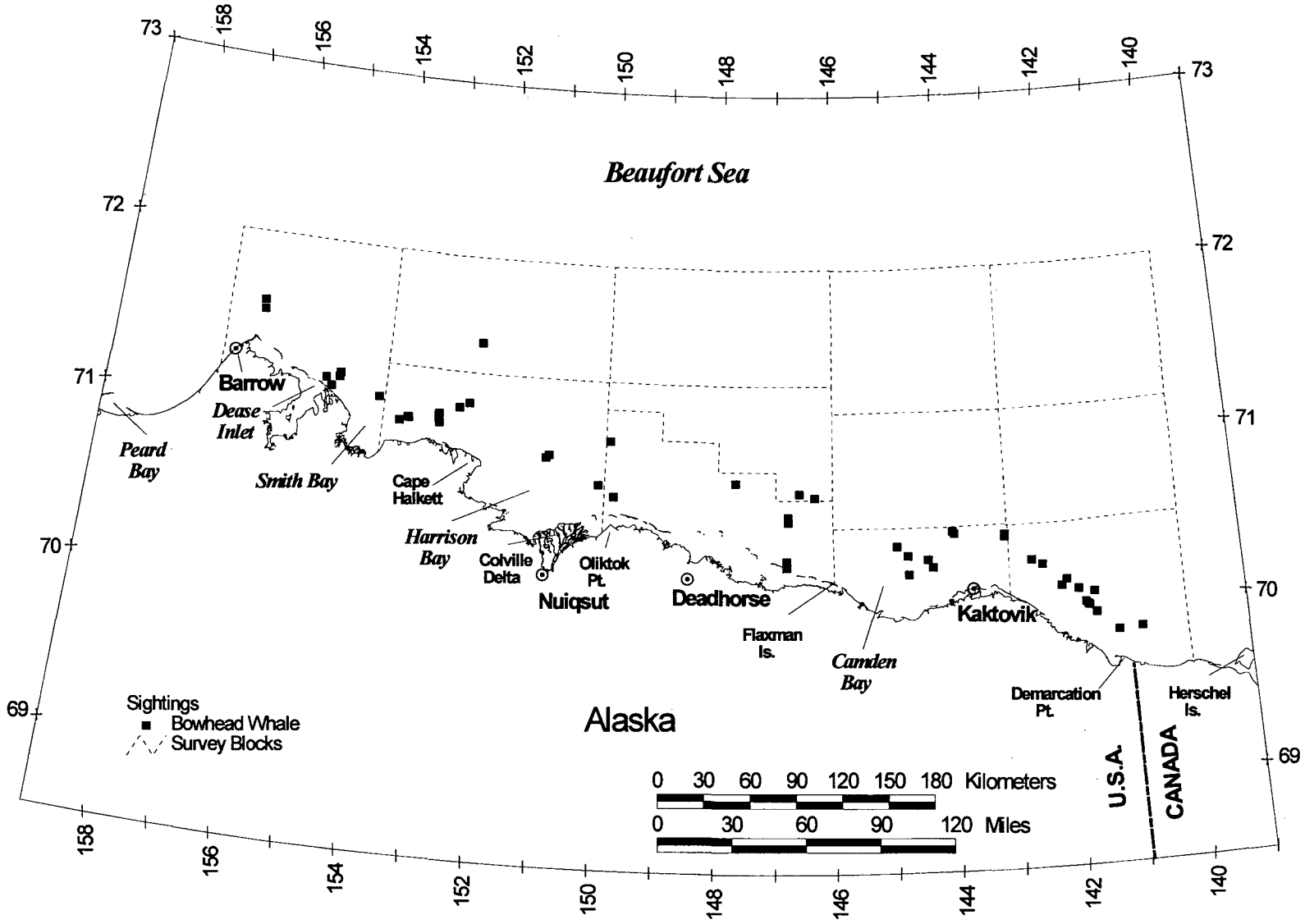

Figure 28. Map of Bowhead Whale Sightings, 16-30 September 1999

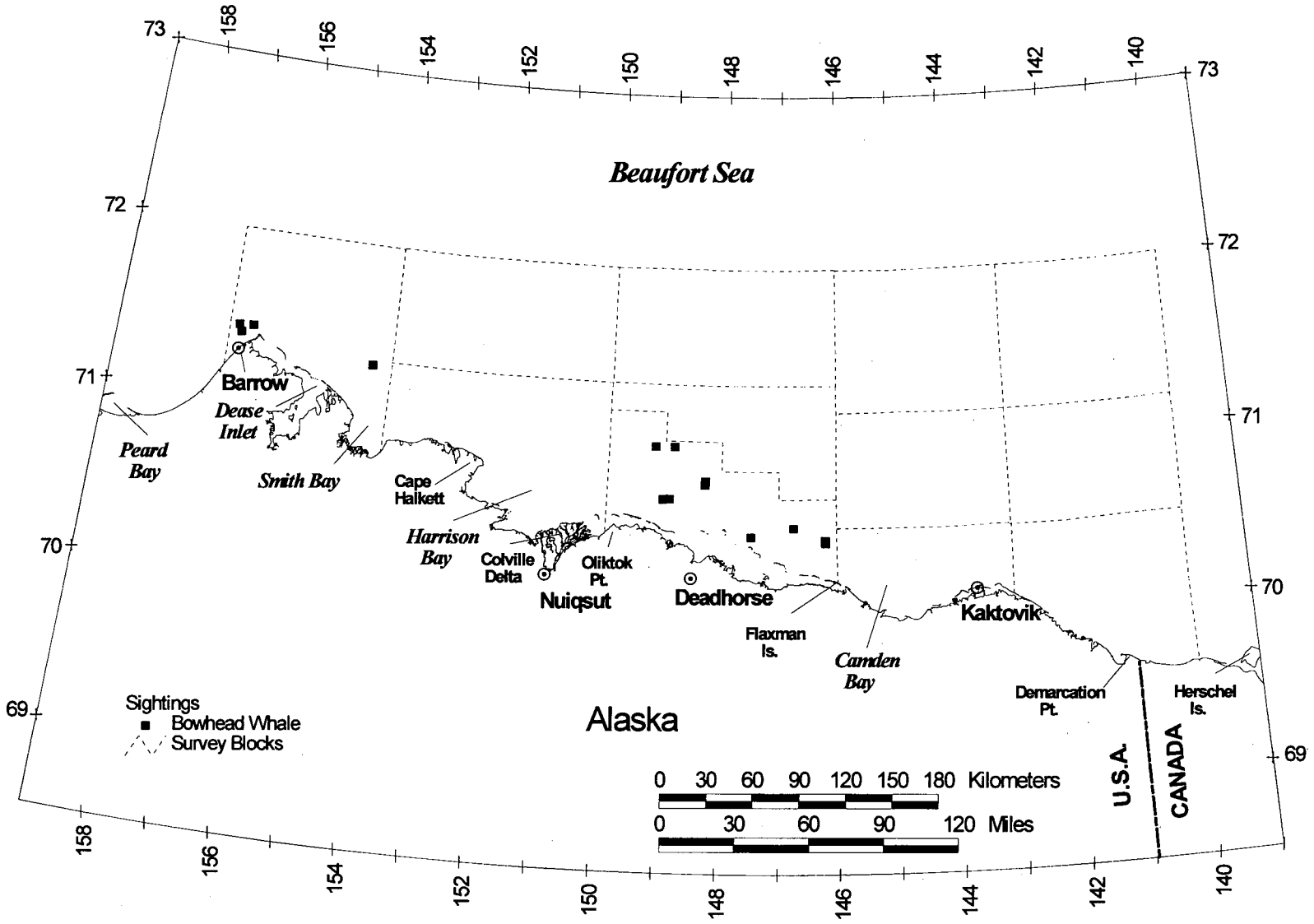

Figure 29. Map of Bowhead Whale Sightings, 1-15 October 1999

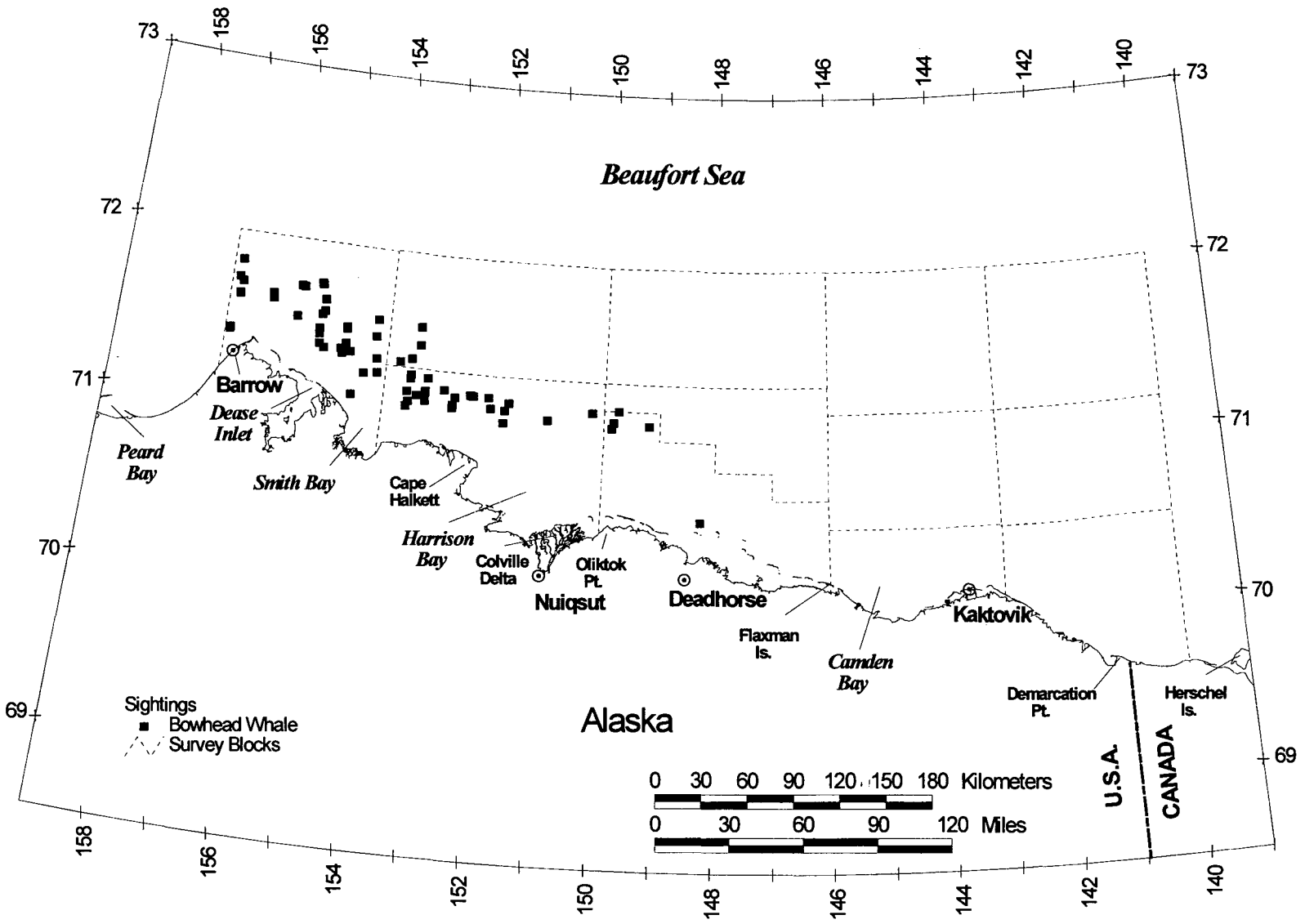

Figure 30. Map of Bowhead Whale Sightings, 16-23 October 1999

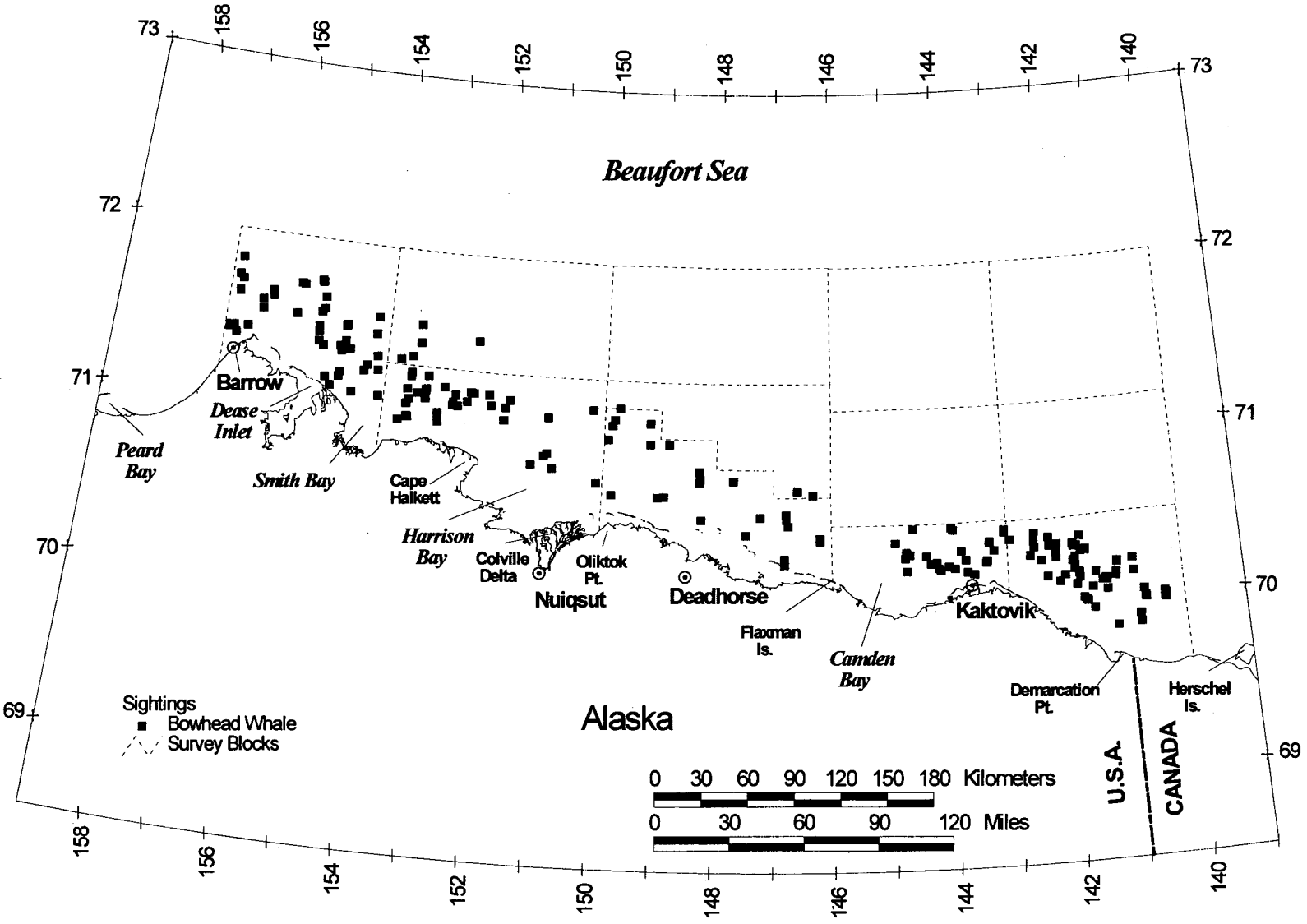

Figure 31. Map of Bowhead Whale Sightings, Fall 1999

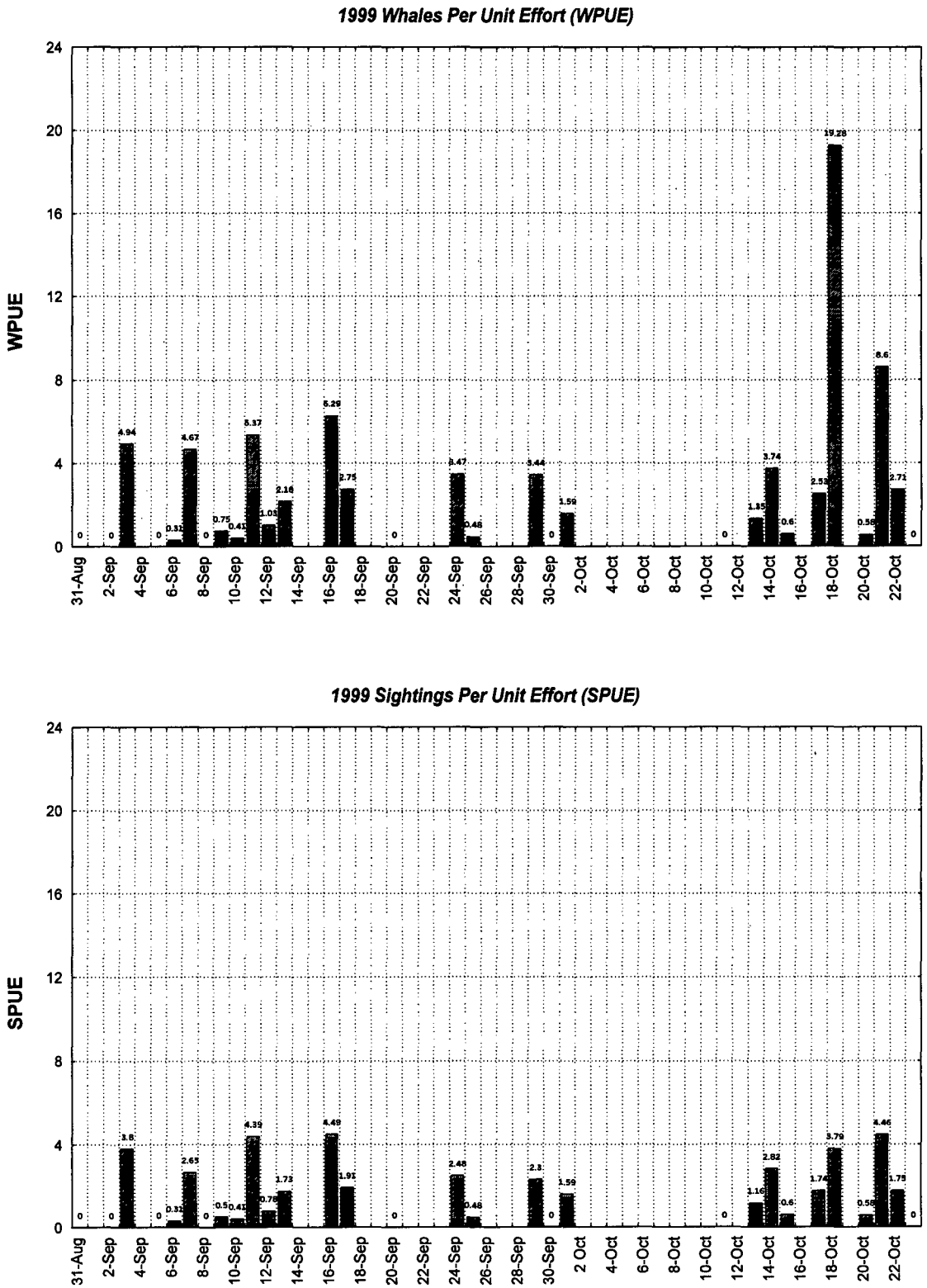

Figure 32. Daily Relative Abundance (WPUE) and Sighting Rate (SPUE) of Bowhead Whales, 31 August – 23 October 1999
(Zeros indicate days when flights were made but no whales were observed.)

recorded) occurred on 17 October. The peak count (mode) of 117 whales (19.28 WPUE) occurred on 18 October (Table 9 and Fig. 32).

The most prominent differences in pattern between the graph for relative abundance and that for sighting rate occurred on 18 October (Fig. 32), due to two large pods of whales observed on those days (Appendix D: Table D-1).

3. Habitat Associations: In addition to general ice coverage for arctic waters in 1999 (Appendix B), the percentage of ice cover visible from the aircraft at each bowhead sighting (Appendix D: Table D-1) was summarized. Over the field season, 226 whales (57%) were sighted in open water (0% sea ice), with declining proportions of whales were observed in open water as the season progressed. In September, all 174 whales (100%) were in open water; from 1-15 October, 8 whales (44%) were in open water; and from 16-23 October, 44 whales (21%) were in open water. From 16-23 October, 109 whales (53%) were observed in 91- through 99-percent concentrations of sea ice (Table 10).

A description of water depth associated with the bowhead migration appears in the water-depth analyses in Section V.A.2.

4. Behaviors: Of 397 bowhead whales observed during Fall 1999, 196 (49%) were swimming (moving forward in an apparently deliberate manner), 88 (22%) feeding, 44 (11%) milling, and 26 (7%) resting when first sighted. Less frequent behaviors included 10 (2%) that were diving, 9 (2%) breaching, 4 (1%) in cow-calf associations, 3 (1%) mating, 3 (1%) tail-slapping, and 2 (1%) flipper-slapping (Table 11). All behaviors noted are defined in Table 1.

On 18 October, one group of 50 and another group of 38 bowhead whales were observed within approx. 15 nm of shore between 153°W. and 154°W. longitudes (Appendix D: Table D-1).

During the 1999 field season, there was one sighting of 2 bowhead whales for which a response to the survey aircraft appeared definite (Appendix C: Table C-1). The pod, swimming slow when first observed, splashed the water as the plane passed by at an altitude of 505 m ASL. Sudden overt changes (e.g., an abrupt dive, course diversion, or cessation of behavior ongoing) in whale behavior were looked for, but no others were observed.

D. Other Marine Mammal Observations

1. Gray Whale (*Eschrichtius robustus*): Over the 1999 season, 1 incidental sighting was made for a total of 2 gray whales (Table 8). The pod was feeding just west of Barrow on 24 September (Fig.33). One unidentified whale, observed on 11 September at 70°13.7′N. latitude, 141°51.4′W. longitude, was thought to be a gray whale, although we were unable to relocate it to confirm the species.

2. Beluga Whale (*Delphinapterus leucas*): Over the Fall 1999 field season, 86 sightings were made for a total of 446 beluga whales (Table 8) during 114.16 hr of survey effort (Table 7) and a seasonal relative abundance of 3.91 WPUE. Beluga whales were sighted beginning 3 September through 22 October across the study area, mostly between 40 and 70 nm from shore, south of 72°N. latitude. A few pods near the Kaktovik and Barrow were closer to shore (Fig. 34). Sizes of pods (or close aggregations of pods) ranged from 1 to 62 whales, with a mean of 5.19 (SD=8.67, n=86). Twenty-seven beluga calves were noted for a calf ratio of 0.06. From 3 September through 13 October, all but one of the belugas was observed in open water (0% sea ice). From 14-22 October, most of the belugas were associated with 50- through 99-percent sea ice.

3. Bearded Seal (*Erignathus barbatus nauticus*): Over the 1999 season, 69 incidental sightings were made for a total of 81 bearded seals (Table 8). Bearded seals were mostly observed during September, east of Deadhorse (Fig. 35). Since survey effort in this area was mostly nearshore (Figs. 22-26), most of

Table 10
Semimonthly Summary of Bowhead Whales Observed,
by Percent Ice Cover Present at Sighting Location, Fall 1999

% Ice Cover	1-15 Sep	16-30 Sep	1-15 Oct	16-23 Oct	Total
0	96 (100%)	78 (100%)	8 (44%)	44 (21%)	226 (57%)
1-5	0	0	0	6 (3%)	6 (2%)
6-10	0	0	0	2 (1%)	2
11-20	0	0	0	0	0
21-30	0	0	0	0	0
31-40	0	0	0	4 (2%)	4 (1%)
41-50	0	0	0	16 (8%)	16 (4%)
51-60	0	0	0	0	0
61-70	0	0	0	0	0
71-80	0	0	0	2 (1%)	2
81-90	0	0	1 (6%)	22 (11%)	23 (6%)
91-99	0	0	9 (50%)	109 (53%)	118 (30%)
TOTAL	96 (100%)	78 (100%)	18 (100%)	205 (100%)	397 (100%)

Table 11
Semimonthly Summary of Bowhead Whales Observed, by Behavioral Category, Fall 1999

Behavior	1-15 Sep	16-30 Sep	1-15 Oct	16-23 Oct	Total
Breach	1 (1%)	0	0	8 (4%)	9 (2%)
Cow-Calf	2 (2%)	0	0	2 (1%)	4 (1%)
Dive	5 (5%)	4 (5%)	0	1 (1%)	10 (2%)
Feed	0	0	0	88 (43%)	88 (22%)
Flipper Slap	2 (2%)	0	0	0	2 (1%)
Mate	0	0	0	3 (1%)	3 (1%)
Mill	12 (13%)	20 (26%)	0	12 (6%)	44 (11%)
Rest	6 (6%)	2 (2%)	6 (33%)	12 (6%)	26 (7%)
Swim	61 (64%)	49 (63%)	12 (67%)	74 (36%)	196 (49%)
Tail Slap	0	0	0	3 (1%)	3 (1%)
Unknown	7 (7%)	3 (4%)	0	2 (1%)	12 (3%)
TOTAL	96 (100%)	78 (100%)	18 (100%)	205 (100%)	397 (100%)

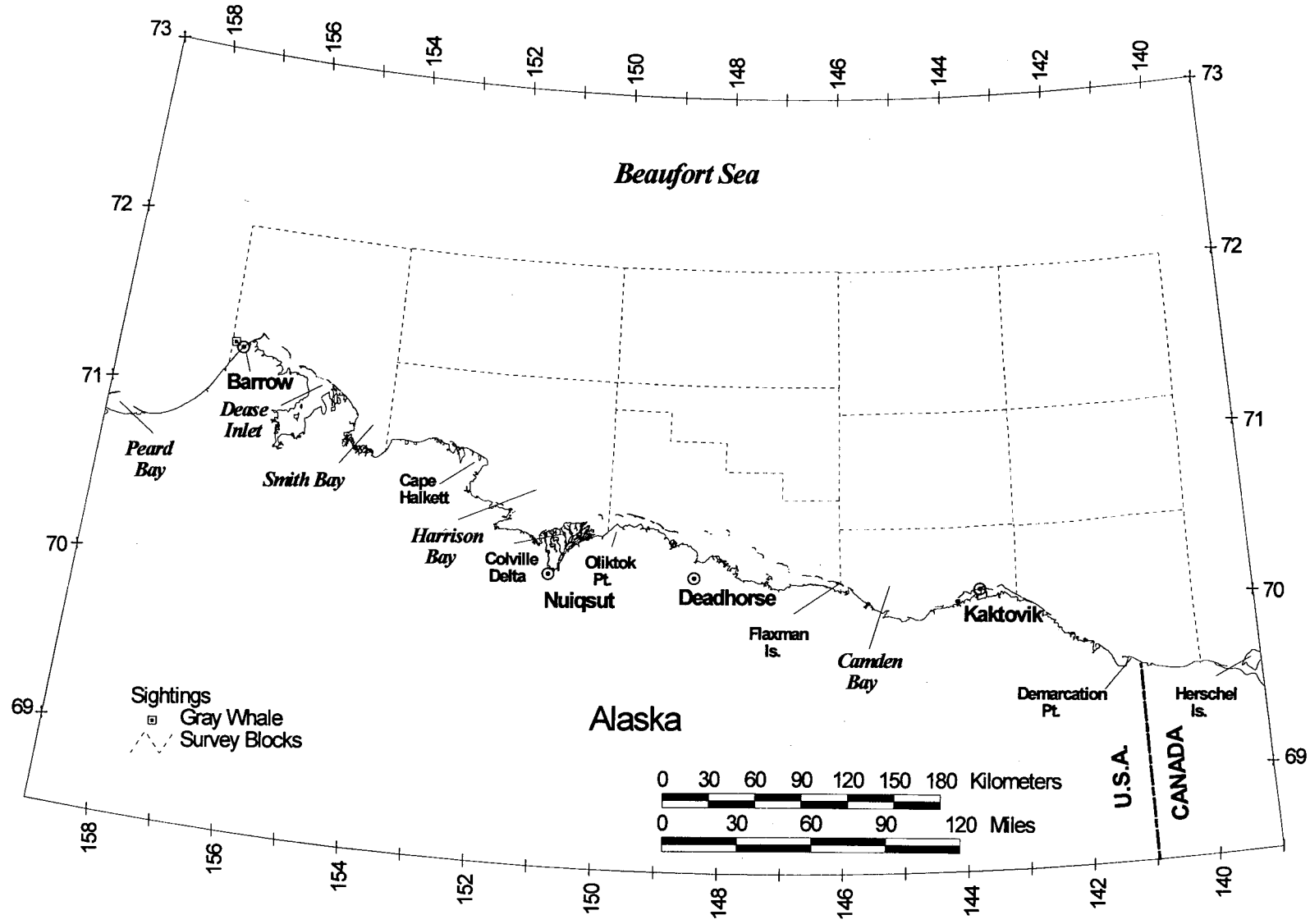

Figure 33. Map of Gray Whale Sightings, Fall 1999

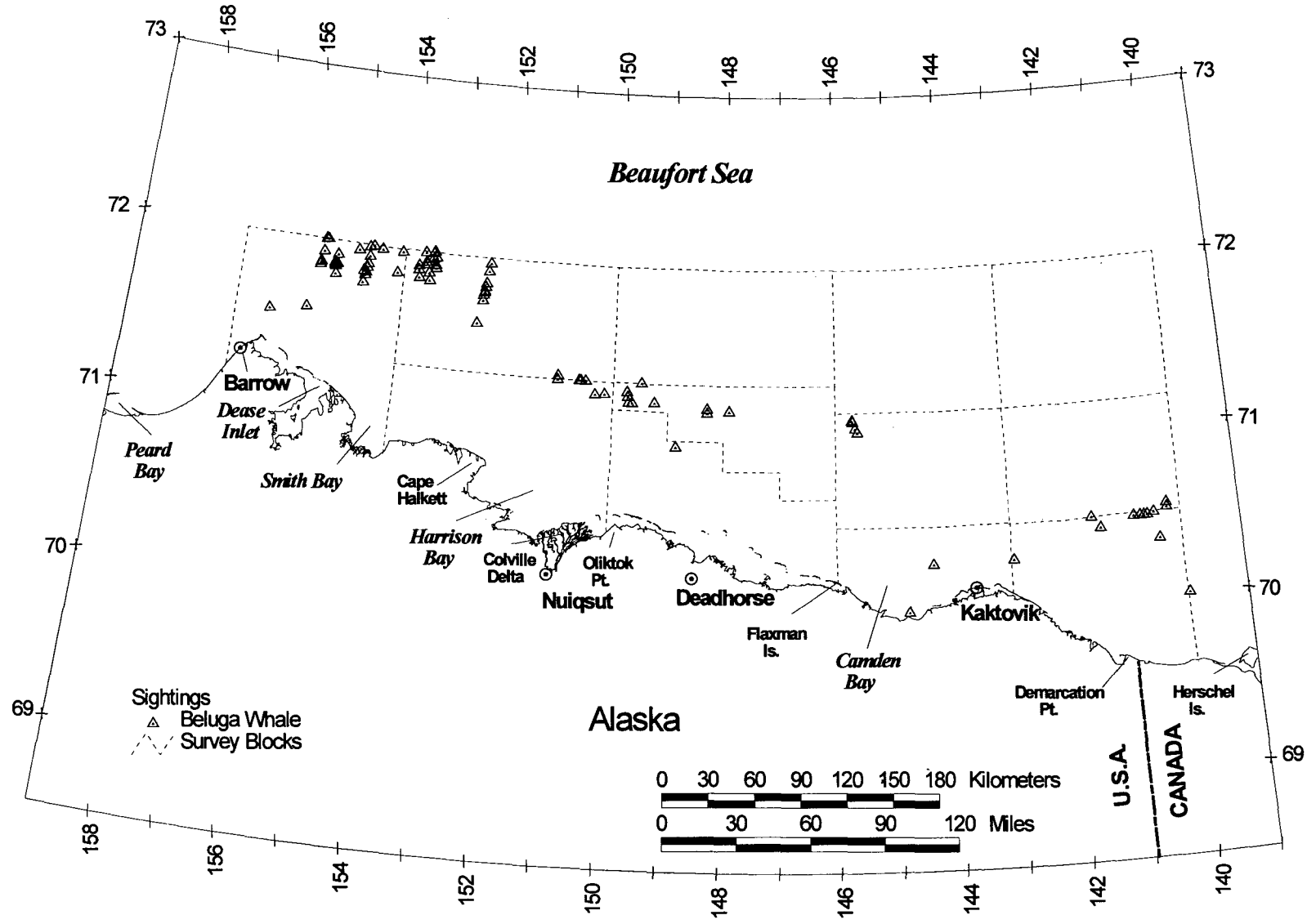

Figure 34. Map of Beluga Whale Sightings, Fall 1999

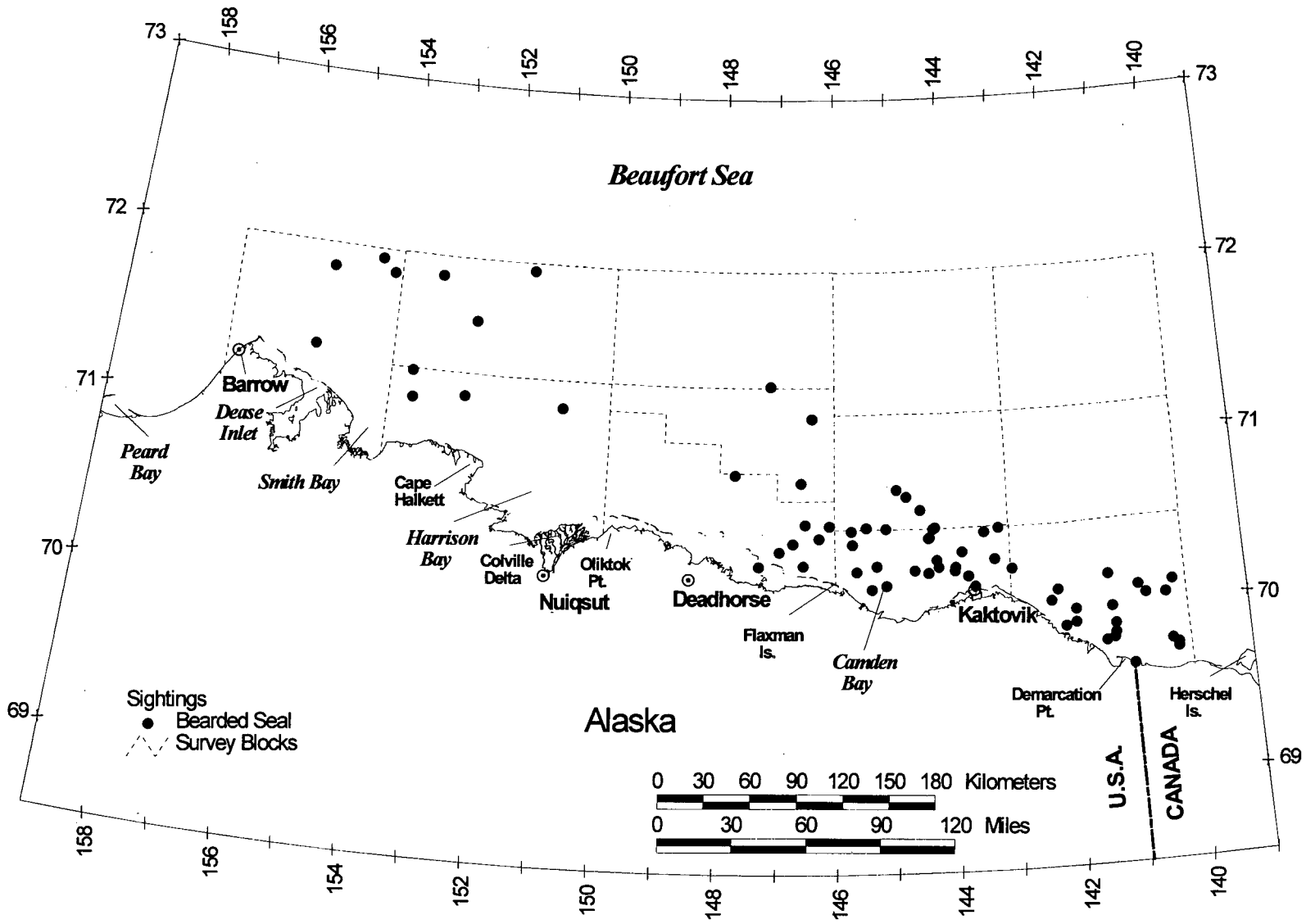

Figure 35. Map of Bearded Seal Sightings, Fall 1999

these eastern sightings were within 40 nm north of the shoreline. All but one of the bearded seals were in open water (0% sea ice).

4. Ringed Seal (*Pusa hispida hispida*): Over the 1999 season, 259 incidental sightings were made for a total of 1,325 ringed seals (Table 8). Ringed seals were mostly observed during September. Some sightings were clustered between 30 nm and 80 nm north of the Colville Delta. Many other sightings were east of Deadhorse (Fig. 36). Since survey effort east of Deadhorse was mostly nearshore (Figs. 22-26), most of these eastern sightings were within 60 nm north of the shoreline (Fig. 36). All but two of the ringed seals were in open water (0% sea ice) when sighted.

5. Walrus (*Odobenus rosmarus divergens*): No walruses were sighted during the 1999 season (Table 8).

6. Unidentified Cetaceans and Pinnipeds: Over the 1999 season, 1 incidental sighting of a large whale (probably a gray whale) was made. Nine sightings were made for a total of 19 unidentified pinnipeds (Table 8).

7. Polar Bear (*Ursus maritimus marinus*): Over the 1999 season, 23 incidental sightings were made for a total of 37 polar bears (Table 8). Most of the bears were on barrier islands near Kaktovik or just east of Deadhorse (Fig. 37). In addition to the polar bear sightings, 70 sets of polar bear tracks were recorded for which no bear was present. Most of the tracks were noted well offshore between 146°W. and 155°W. longitudes starting 15 October when ice began covering the study area (Table 8, Fig. 38, Appendix B).

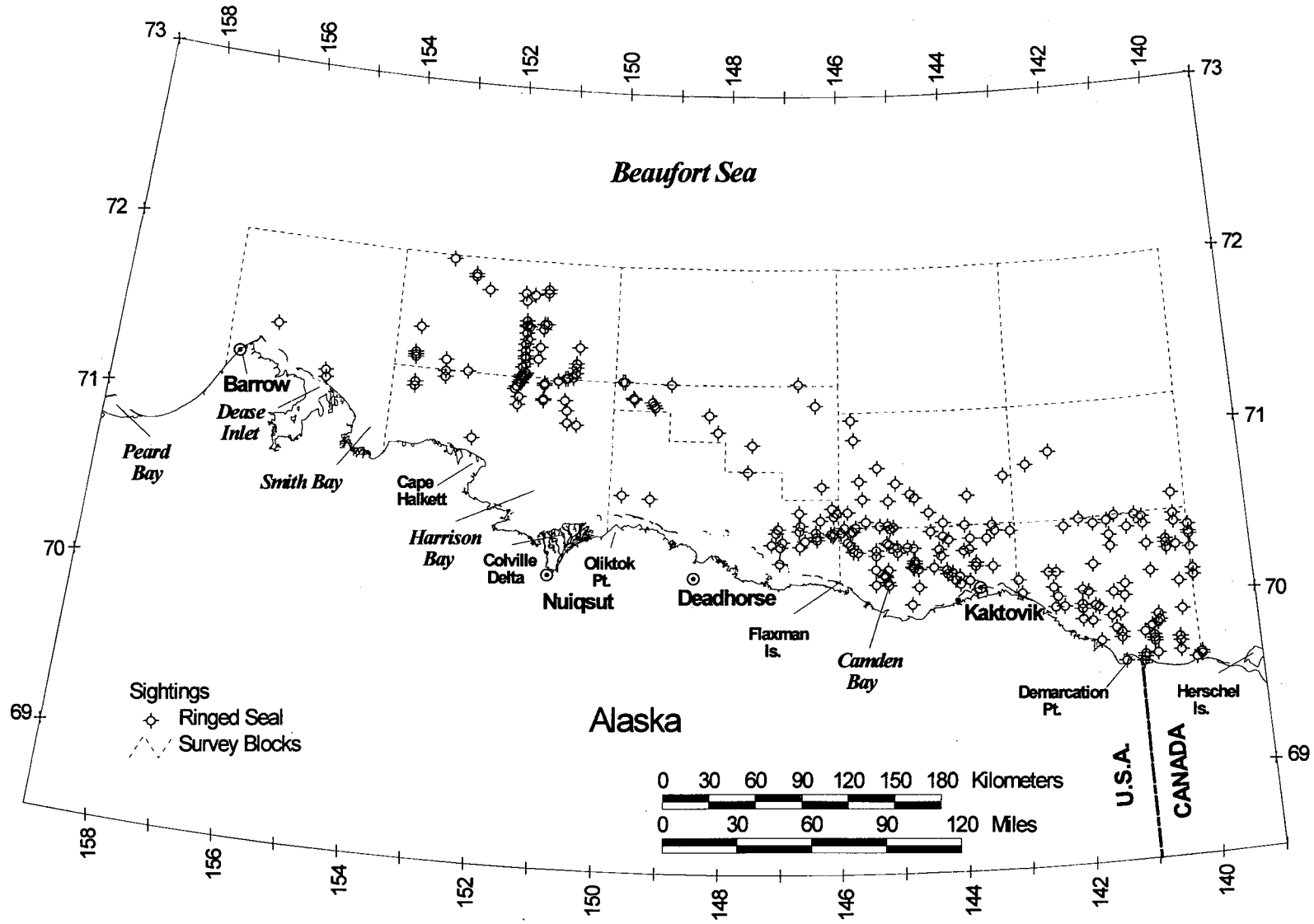

Figure 36. Map of Ringed Seal Sightings, Fall 1999

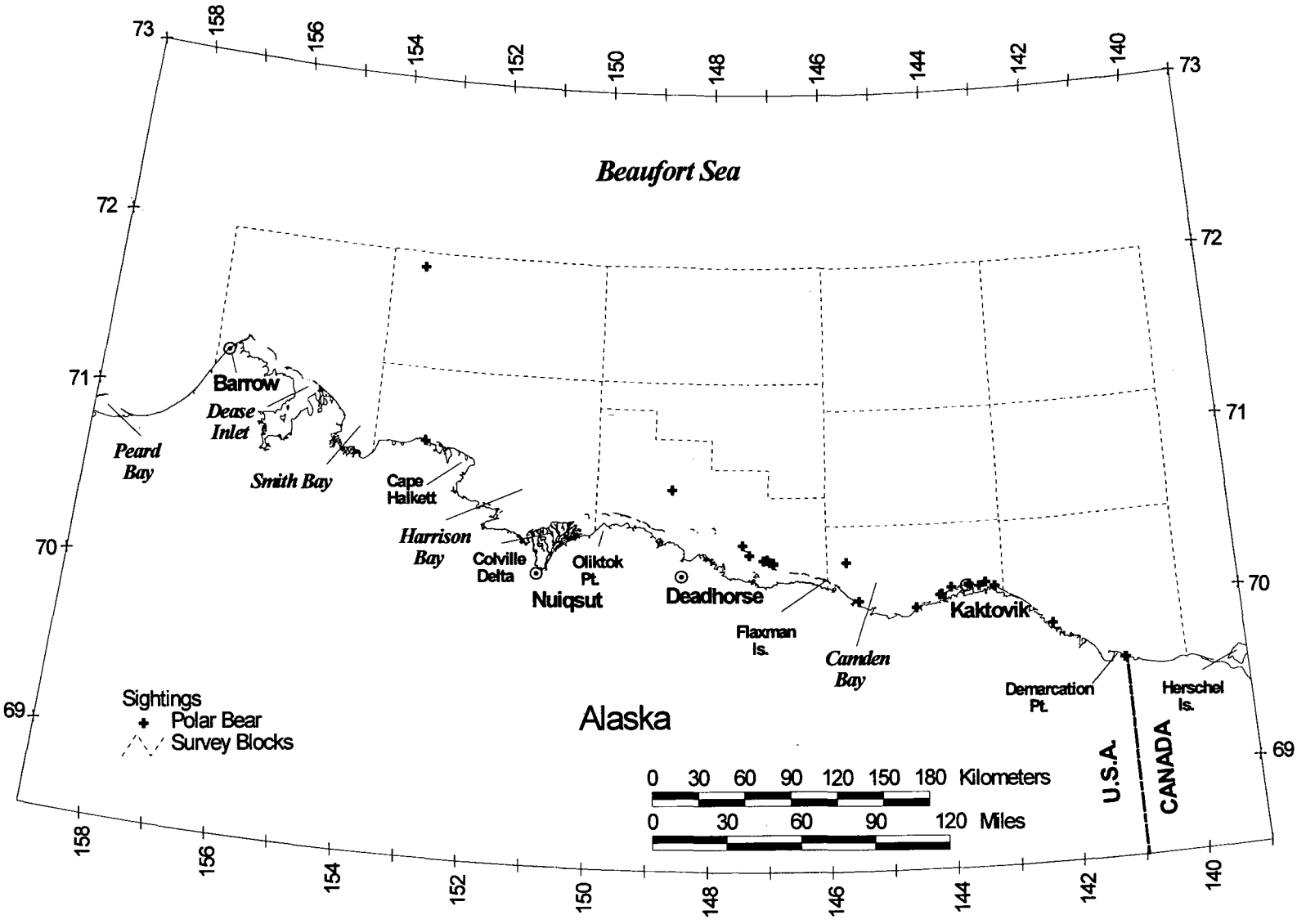

Figure 37. Map of Polar Bear Sightings, Fall 1999

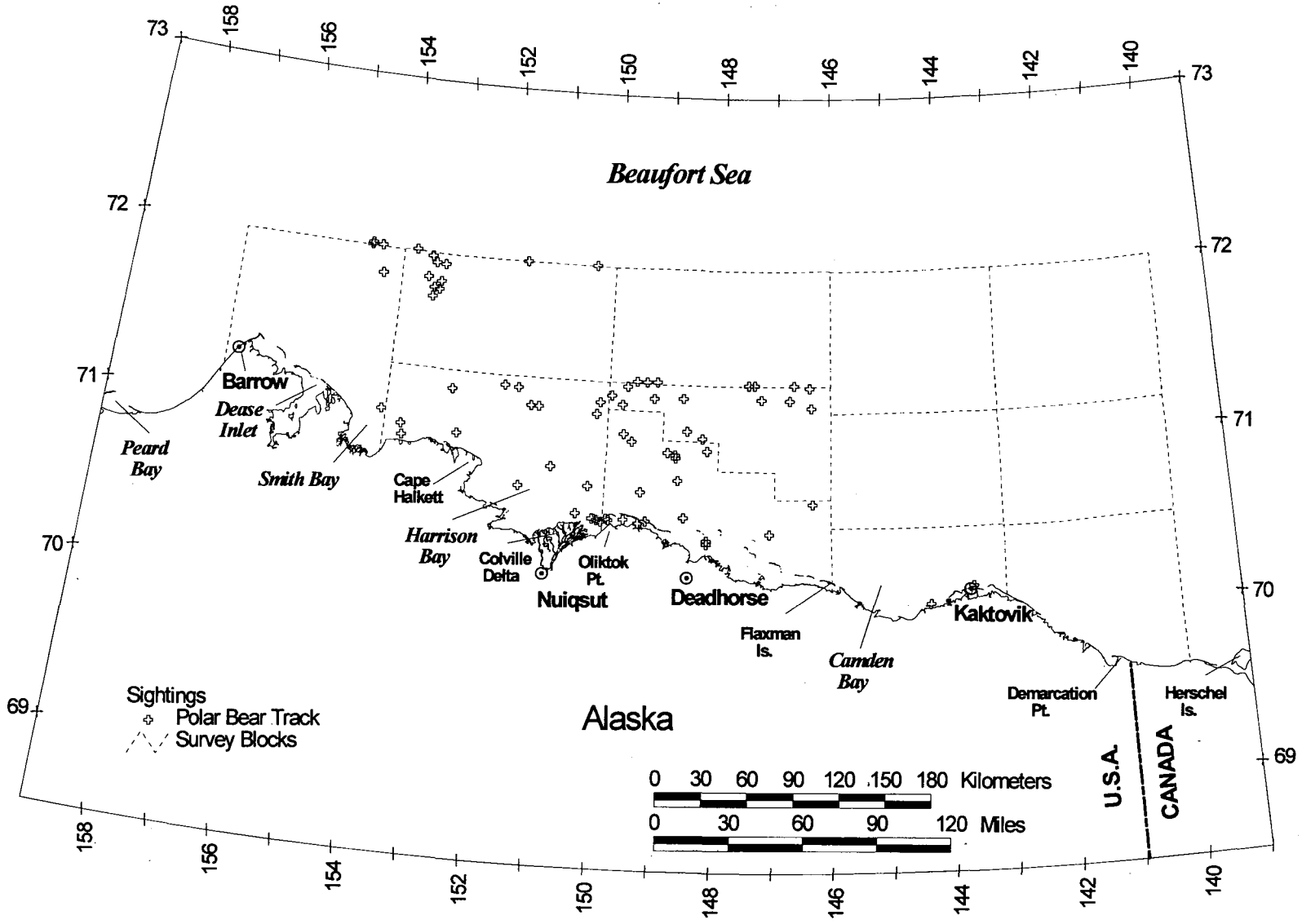

Figure 38. Map of Polar Bear Tracks, Fall 1999

V. INTERANNUAL RESULTS (1979-1999)

A. Statistical Analyses of the Bowhead Whale Migration Corridor (1982-1999)

1. Central Tendency Statistics - Distance from Shore: Transect data were analyzed over a 18-year period (1982-1999) in two regions of the Alaskan Beaufort Sea (Fig. 2). Annual central-tendency statistics for distance of bowhead whales from shore were summarized by year and region (Table 12 and Fig. 39). The mean distance of the whale migration from shore in each region was also depicted visually for Fall 1998 (Fig. 41) and for Fall 1999 (Fig. 42).

East Region

The combined data (1982-1999) included 666 transect sightings (trSI) in the East Region. Mean measures of distance from shore among years ranged from 15.1 km (in 1997) to 89.7 km (in 1983). The Confidence Interval (CI) about the mean was widest (>30 km) in 1988 and 1989, each of which had a small sample size (<10 trSI) (Table 12 and Fig. 39).

West Region

The combined data (1982-1999) included 584 transect sightings in the West Region. Mean measures of distance from shore ranged from 24.8 km (in 1994) to 65.9 km (in 1988). The CI about the mean was widest (>30 km) in 1985, 1987, 1990, 1991, and 1994, each of which had a small sample size (<10 trSI). The axis of the bowhead migration in the West Region was nearer to shore (median = 20.9 km) during Fall 1998 than for any previous year, 1982-1999 (Table 12 and Fig. 39).

2. Central Tendency Statistics - Water Depth: The transect data were analyzed over a 18-year period (1982-1999) in two regions of the Alaskan Beaufort Sea (Fig. 2). Annual central-tendency statistics for water depth at bowhead whale sightings were summarized by year and region (Table 13 and Fig. 40). Although water depths for individual whales using the higher resolution IPCAO bathymetry often differed from depths noted for these same whales in previous years, the annual median water depths (Fig. 40) appear remarkably similar to medians derived with a previously used DEPTH program (Treacy, 1998: Figure 28).

East Region

The combined data (1982-1999) included 666 transect sightings in the East Region. Annual mean depths ranged from 23.9 m (in 1997) to 915.5 m (in 1983). The CI about the mean was widest (>100 m) in 1983, 1988, 1989, 1991 and 1994, four of which had a small sample size (<20 trSI). The 25^{th} - 75^{th} quartiles about the median were widest apart (>35 m) in 1983, 1989, and 1991 (Table 13 and Fig. 40).

West Region

The combined data (1982-1999) included 584 transect sightings in the West Region. Annual mean depths ranged from 18.7 m (in 1989) to 312.7 m (in 1983). The CI about the mean was widest (>100 m) in 1982, 1983, 1985, 1986, 1991, 1992, and 1995, four of which had a small sample size (<20 trSI). The 25^{th}-75^{th} quartiles about the median were widest apart (>35 m) in 1983, 1985, 1986, and 1991. The axis of the bowhead migration in the West Region was in shallower water (median = 15.2 m) during Fall 1998 than for any previous year (1982-1999) except for 1994 (Table 13 and Fig. 40).

3. ANOVA - Distance from Shore: A parametric ANOVA of distances from shore over an 18-year period (1982-1999) regardless of sample size indicated strongly significant differences among years for the East Region ($F=10.19$, $p<0.001$) and for the West Region ($F=19.42$, $p<0.001$). A previous analysis (1982-1997) comparing only years having a larger sample size ($n\geq20$ trSI), for which a power analysis was performed, also showed strongly significant differences among years (Treacy, 1998).

4. Tukey HSD Test - Distance from Shore: Since the ANOVA showed significant differences among years, the Tukey HSD test was applied to all transect sightings of bowhead whales over an 18-year period (1982-1999) without exclusions to determine which years were significantly different from each other.

Table 12
Central-Tendency Statistics for Distance from Shore (in kilometers) to Random Sightings of Bowhead Whales (September-October), by Year and Region, 1982-1999

Year	Region	trSI [1]	Median	25th-75th Quartile Range	Mean	SD [2]	CI [3]	Range
1982	East	28	36.9	31.5-43.2	38.2	8.5	34.9-41.5	26.0-56.6
	West	26	41.7	37.7-48.9	43.7	16.7	36.9-50.4	14.6-86.3
1983	East	14	89.5	82.0-98.9	89.7	15.7	80.7-98.8	59.6-121.2
	West	15	53.3	42.3-86.6	62.2	26.3	47.6-76.7	27.5-125.3
1984	East	23	36.6	25.6-56.5	39.7	23.9	29.3-50.0	1.9-103.4
	West	36	46.2	36.8-60.3	45.7	19.2	39.2-52.2	8.9-85.2
1985	East	10	29.5	23.7-40.5	31.8	16.0	20.4-43.3	1.9-61.4
	West	7	50.3	25.9-86.3	53.8	29.2	26.8-80.8	15.4-88.9
1986	East	30	27.5	16.7-39.8	27.8	16.7	21.5-34.0	1.0-58.1
	West	19	38.8	24.7-52.4	39.9	22.8	28.9-50.9	3.7-81.7
1987	East	30	33.5	18.5-50.1	37.0	20.7	29.3-44.7	6.9-86.1
	West	8	29.2	16.7-51.2	32.7	20.2	15.9-49.6	7.4-60.3
1988	East	6	29.5	24.4-33.9	33.4	23.5	8.8-58.0	6.4-76.8
	West	8	64.5	59.1-71.4	65.9	11.2	56.6-75.3	50.7-86.8
1989	East	6	55.8	49.3-89.4	63.4	23.4	38.8-87.9	36.1-94.0
	West	17	35.4	15.6-45.8	32.8	19.4	22.8-42.8	7.5-74.5
1990	East	93	33.8	25.4-43.0	34.5	13.8	31.7-37.4	8.1-78.6
	West	6	35.8	32.3-48.2	42.5	18.5	23.1-61.9	25.9-77.3
1991	East	14	62.4	39.4-76.7	59.2	20.5	47.4-71.1	34.5-85.6
	West	6	46.0	34.1-72.3	51.5	18.8	31.7-71.2	33.6-76.8
1992	East	12	38.2	34.3-51.6	42.5	10.9	35.6-49.4	28.5-60.5
	West	13	61.1	45.1-74.3	59.3	17.2	48.9-69.7	29.9-82.2
1993	East	55	30.3	21.2-40.4	31.9	17.0	27.3-36.5	6.4-88.4
	West	35	25.1	20.4-38.6	29.9	12.7	25.6-34.3	11.8-62.7
1994	East	32	29.4	22.4-56.2	37.2	18.7	30.4-44.0	13.9-77.7

Table 12
Central-Tendency Statistics for Distance from Shore (in kilometers) to Random Sightings of Bowhead Whales (September-October), by Year and Region, 1982-1999

Year	Region	trSI [1]	Median	25th-75th Quartile Range	Mean	SD [2]	CI [3]	Range
	West	3	23.3	[4]	24.8	11.5	[4]	14.1-36.9
1995	East	94	30.2	23.6-41.6	33.1	16.4	29.7-36.5	3.7-99.5
	West	44	36.5	25.3-51.7	42.9	26.5	34.8-50.9	7.6-118.7
1996	East	13	29.4	21.0-34.6	29.1	11.4	22.2-36.0	15.3-57.6
	West	15	40.6	23.6-55.1	40.8	14.8	32.6-49.1	21.4-64.1
1997	East	35	10.2	5.9-20.4	15.1	11.9	11.0-19.1	3.4-44.9
	West	145	27.4	20.0-36.3	29.2	13.0	27.1-31.3	1.0-66.0
1998	East	103	22.2	13.6-31.3	23.8	13.0	21.3-26.3	4.0-73.8
	West	113	20.9	14.7-32.5	26.3	18.6	22.8-29.8	1.1-124.0
1999	East	68	40.2	28.5-49.7	39.5	13.5	36.3-42.8	-0.1[5]-65.8
	West	68	36.1	27.0-52.1	39.3	17.5	35.1-43.6	9.2-75.6
Cumulative	East	666	31.7	20.9-43.3	34.1	19.2	32.7-35.6	-0.1[5]-121.2
(1982-99)	West	584	33.4	20.6-47.6	36.0	20.3	34.4-37.7	1.0-125.3

[1] trSI = number of transect sightings.
[2] SD = standard deviation.
[3] CI ≥ 95-percent confidence interval (positive values).
[4] Insufficient sample size.
[5] Negative value is for one transect sighting between the actual and normalized coastline.

Table 13
Central-Tendency Statistics for Water Depth (in meters) at Random Sightings of Bowhead Whales (September-October), by Year and Region, 1982-1999

Year	Region	trSl [1]	Median	25th-75th Quartile Range	Mean	SD [2]	CI [3]	Range
1982	East	28	42.1	38.6-49.0	43.5	6.4	41.0-46.0	34.9-57.3
	West	26	30.3	22.8-37.4	94.0	210.9	8.9-179.2	14.3-1041.5
1983	East	14	804.0	263-1779	915.5	718.8	501-1331	64.6-1952.8
	West	15	68.3	33.7-209.1	312.7	597.9	18.4-643.9	20.7-2165.7
1984	East	23	43.9	35.2-54.3	77.0	104.8	31.7-122.3	17.8-507.9
	West	36	40.3	31.7-55.6	47.7	33.2	36.5-59.0	12.8-189.2
1985	East	10	38.3	34.8-40.8	37.5	7.4	32.3-42.8	22.8-51.0
	West	7	35.7	23.9-148.1	193.3	348.5	129-515.6	16.1-974.7
1986	East	30	41.1	24.0-50.2	38.1	18.2	31.4-44.9	6.8-91.5
	West	19	28.3	18.9-75.1	77.9	117.4	21.3-134.6	9.6-489.7
1987	East	30	39.7	32.7-54.3	56.3	47.9	38.4-74.2	14.9-223.3
	West	8	25.2	13.1-31.6	22.6	10.0	14.2-30.9	8.3-32.4
1988	East	6	48.8	39.1-50.3	92.2	123.5	37.3-221.8	22.9-343.4
	West	8	49.4	46.9-52.7	50.3	6.8	44.6-55.9	40.5-63.5
1989	East	6	60.5	51.1-448.4	196.1	219.7	34.5-426.7	47.3-508.8
	West	17	20.1	11.3-24.1	18.7	8.1	14.5-22.8	5.8-33.8
1990	East	93	42.0	35.9-50.1	47.7	33.0	40.9-54.5	19.6-284.6
	West	6	31.5	22.8-39.2	32.6	11.4	20.6-44.6	20.0-50.6
1991	East	14	68.7	50.5-190.7	128.3	109.6	65.0-191.6	46.3-387.0
	West	6	41.5	35.5-204.8	96.6	94.2	2.2-195.5	26.3-230.2
1992	East	12	53.5	47.1-56.0	51.5	6.0	47.7-55.3	40.5-58.9
	West	13	50.8	43.9-53.6	54.1	27.8	37.3-70.8	14.3-121.3
1993	East	55	40.5	33.5-50.2	58.4	96.5	32.3-84.5	11.4-716.6
	West	35	20.1	16.4-25.4	22.8	9.4	19.6-26.0	10.7-49.3
1994	East	32	46.8	39.0-53.3	79.8	175.6	16.5-143.1	30.7-1037.8

Table 13
Central-Tendency Statistics for Water Depth (in meters) at Random Sightings of Bowhead Whales (September-October), by Year and Region, 1982-1999

Year	Region	trSI [1]	Median	25th-75th Quartile Range	Mean	SD [2]	CI [3]	Range
	West	3	12.0	[4]	21.4	16.6	[4]	11.6-40.5
1995	East	94	41.4	35.7-49.9	52.5	68.7	38.4-66.6	14.9-628.0
	West	44	30.8	25.8-38.8	107.4	259.7	28.4-186.4	6.5-1232.8
1996	East	13	39.4	33.4-45.6	37.7	9.3	32.1-43.3	15.0-48.5
	West	15	34.8	23.6-44.3	37.0	17.1	27.5-46.5	18.6-82.5
1997	East	35	22.1	13.0-32.0	23.9	11.9	19.8-28.0	10.5-50.0
	West	145	20.0	15.7-26.5	25.0	21.4	21.5-28.5	4.7-189.2
1998	East	103	32.4	26.1-40.3	34.2	12.0	31.9-36.6	6.6-82.6
	West	113	15.2	11.6-21.5	37.7	170.8	5.9-69.6	5.4-1814.7
1999	East	68	50.2	39.5-54.6	51.2	20.9	46.2-56.3	7.9-171.3
	West	68	30.7	21.1-41.9	42.6	42.9	32.2-53.0	10.9-210.3
Cumulative	East	666	40.9	33.4-50.6	70.1	173.9	56.8-83.2	6.6-1952.8
(1982-99)	West	584	24.8	16.4-36.4	53.1	161.0	40.0-66.2	4.7-2165.7

[1] trSI = number of transect sightings.
[2] SD = standard deviation.
[3] CI ≥ 95-percent confidence interval (positive values).
[4] Insufficient sample size.

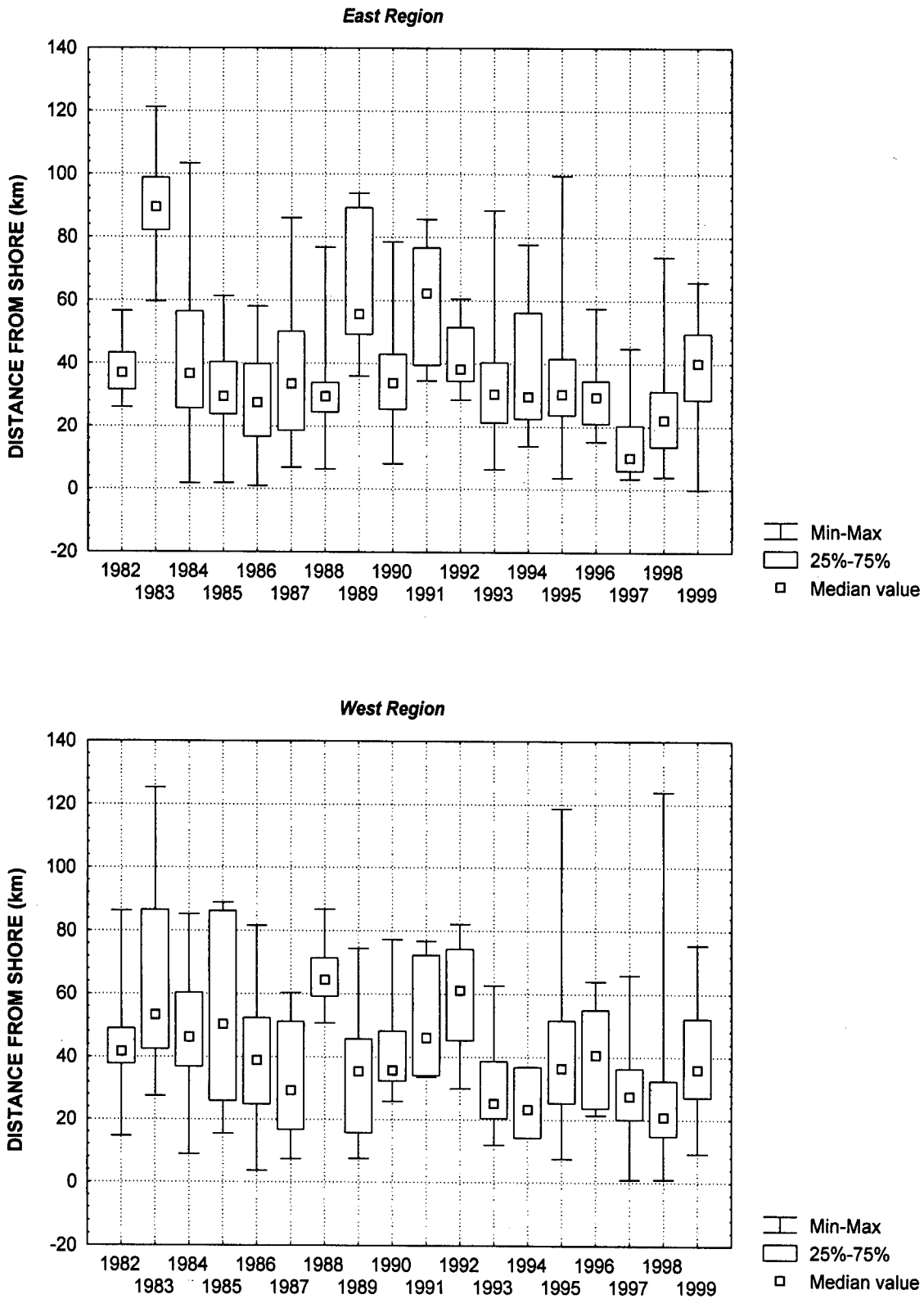

Figure 39. Median Distance from Shore at Random Sightings of Bowhead Whales (September-October), by Year and Region, 1982-1999, showing Quartile and Maximum Ranges

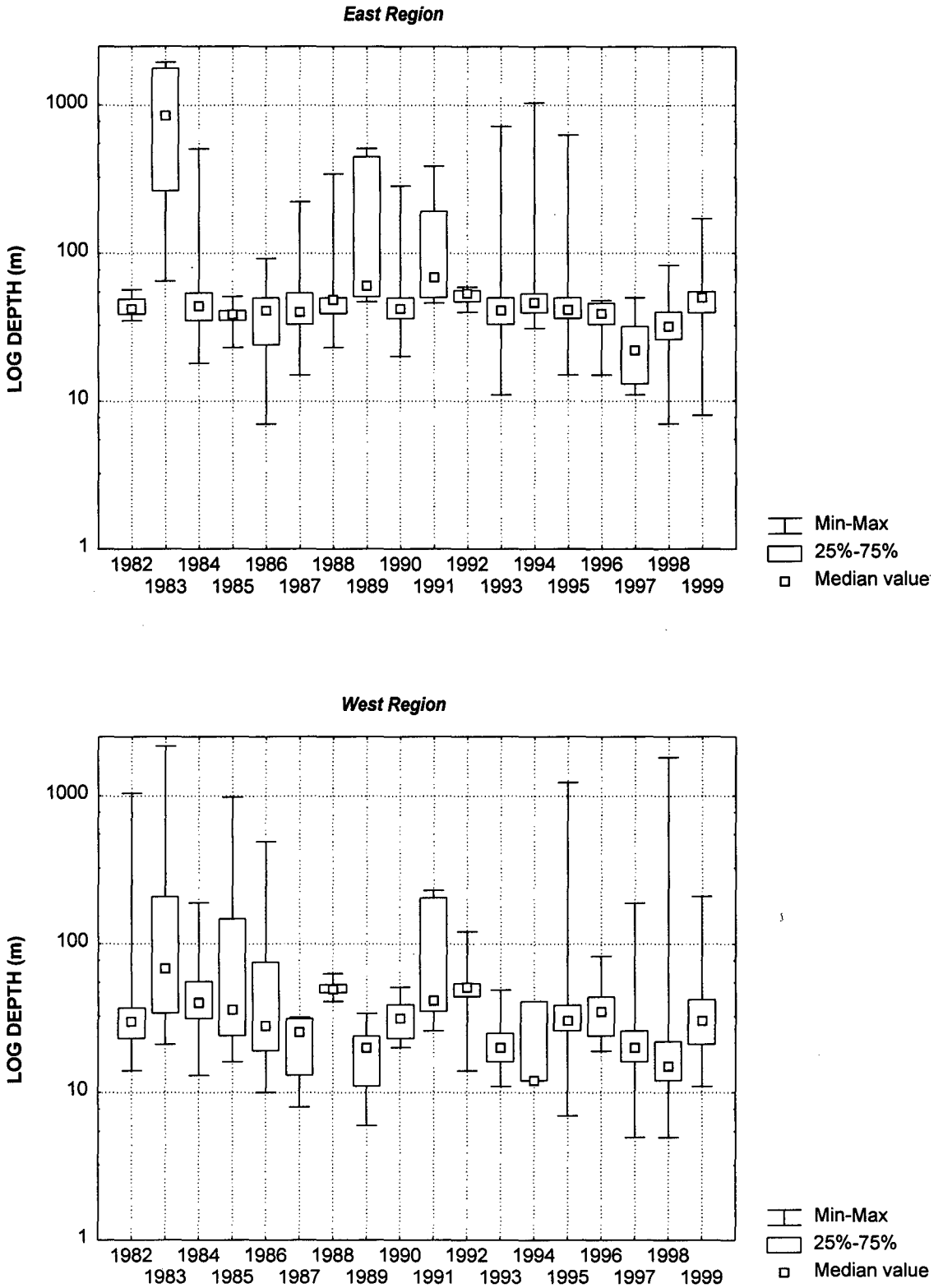

Figure 40. Median Water Depth at Random Sightings of Bowhead Whales (September-October), by Year and Region, 1982-1999, showing Quartile and Maximum Ranges

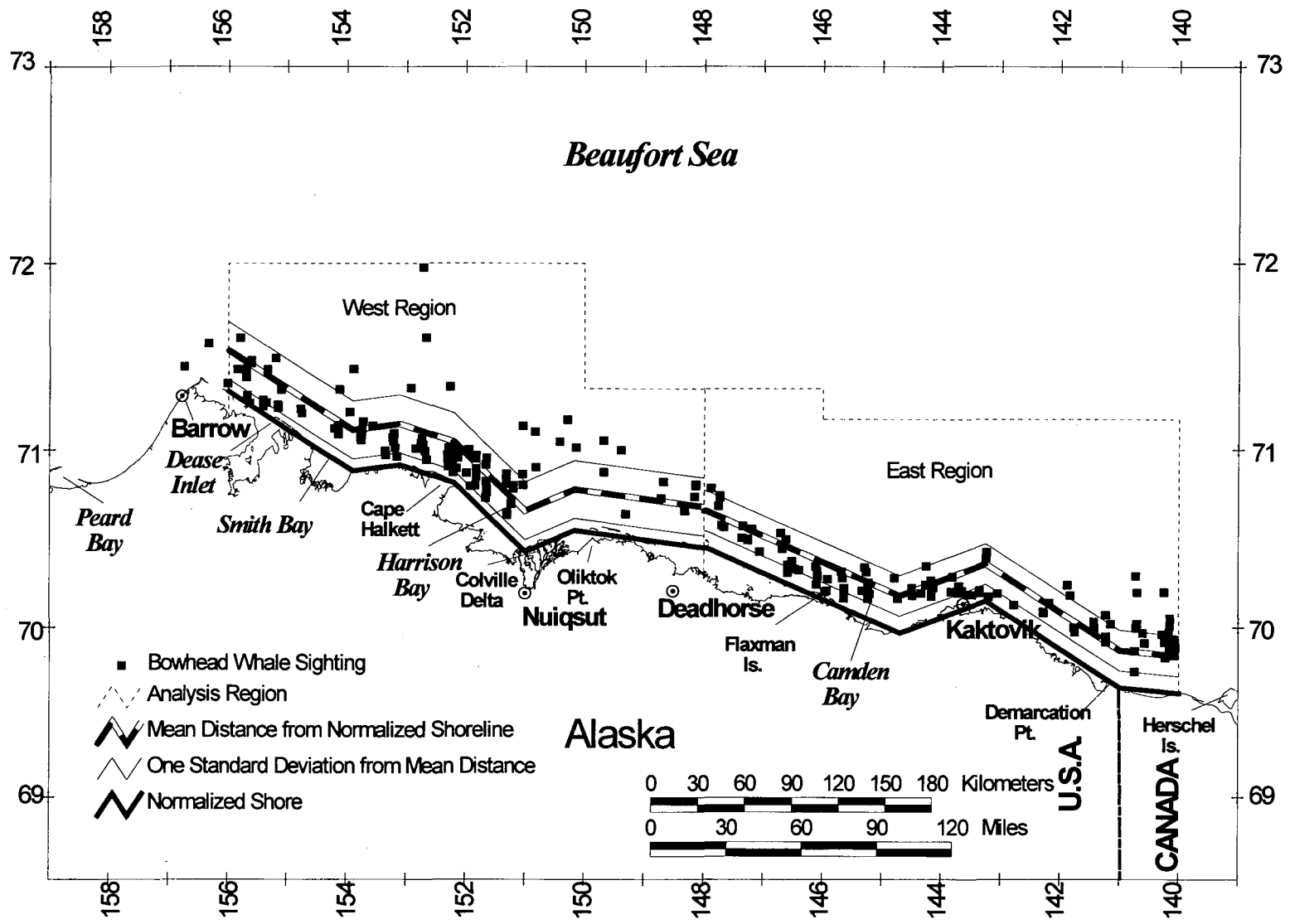

Figure 41. Fall Bowhead Whale Sightings on Transect (1998), Showing Mean Distance from a Normalized Shoreline

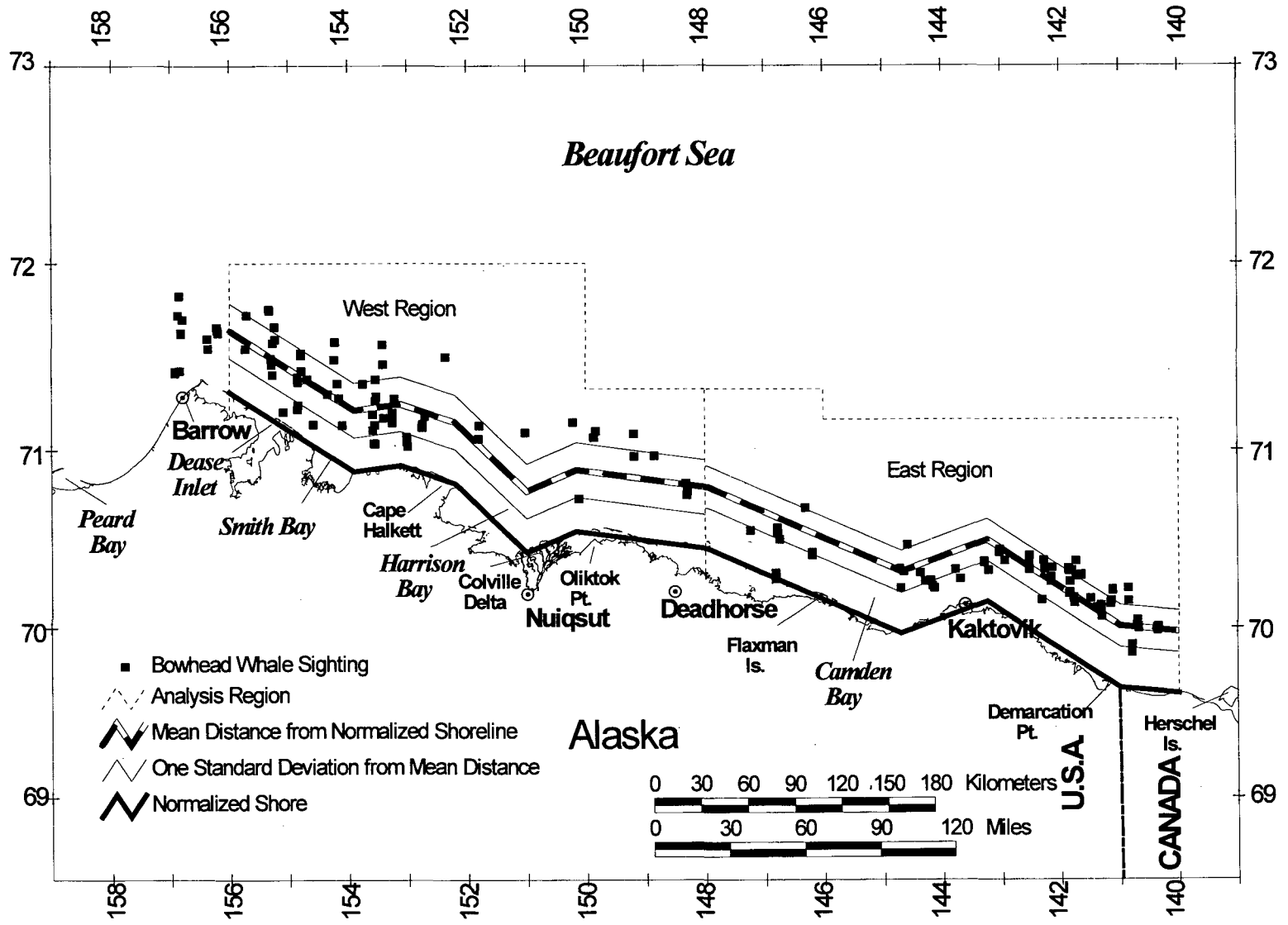

Figure 42. Fall Bowhead Whale Sightings on Transect (1999), Showing Mean Distance from a Normalized Shoreline

East Region

The Tukey test showed that bowheads in 1983 migrated significantly ($p<0.05$) farther offshore than in any other year except 1989. The data also showed that whales in 1989 were significantly farther offshore, and in 1997 were significantly nearer to shore, than for most (>10) other years. The mean for East Region whales in 1998 (Fig. 41) was significantly nearer to shore than in 1999 (Fig. 42).

West Region

The Tukey test showed that in 1983, 1988, 1991, and 1992, bowheads migrated significantly ($p<0.05$) farther offshore than for most (>10) other years. Whales in 1997 and 1998 migrated significantly ($p<0.05$) nearer to shore than for many (>8) other years and were nearer to shore in 1998 than in other years (1982-1999). The mean for West Region whales in 1998 (Fig. 41) was significantly nearer to shore than in 1999 (Fig. 42).

B. General Ice Cover (1979-1999)

General ice coverage along the northern coast of Alaska during the 1998 navigation season was the third-mildest for the 47 years from 1953 through 1999 and showed the greatest distance (240 nm) from Point Barrow northward to the boundary of 5-tenths ice concentration on 15 September. Ice cover during 1999 was the 18th mildest (USDOC, NOAA, National Ice Center/USDOD, Navy, Naval Ice Center, 2000).

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 1999 and showed distances ranging from 10 to 25 nm between Point Barrow and the five-tenths ice concentration on 15 September (USDOC, NOAA, National Ice Center/USDOD, Navy, Naval Ice Center, 2000).

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 1999 and showed distances ranging from 50 to 75 nm between Point Barrow and the five-tenths ice concentration on 15 September (USDOC, NOAA, National Ice Center/USDOD, Navy, Naval Ice Center, 2000).

The years 1979, 1981, 1982, 1986, 1987, 1989, 1990, and 1993-1999, 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 1999 and showed distances ranging from 50 to 240 nm between Point Barrow and the five-tenths ice concentration on 15 September (USDOC, NOAA, National Ice Center/USDOD, Navy, Naval Ice Center, 2000). The recent seven years of unbroken light ice coverage (1993-1999) based on these criteria were not inconsistent with recently hypothesized global and/or cyclical warming.

General ice cover may affect the distance from shore and the water depth at which bowhead whales migrate in the fall. The years with heavy and medium ice cover (1980, 1983, 1984, 1985, 1988, 1991, and 1992) account for the highest median values shown for the West Region (Table 12 and Figs. 39-40). It is in the West Region that the distances from Point Barrow to five-tenths ice concentrations were estimated (USDOC, NOAA, National Ice Center/USDOD, Navy, Naval Ice Center, 2000). It is also where all six of the median distances greater than 42 km and the median water depths greater than 35 m correspond with heavy or medium ice years, thus suggesting that bowheads may migrate farther offshore and in deeper water in icier years. Conversely, the extremely small median distance from shore and median water depth at bowhead sightings in Fall 1998 in the West Region would be consistent with a tendency for bowheads to migrate closer to shore and in shallower water during years of light general ice cover.

C. Key Results Summary (1979-1999)

- General ice severity along the northern coast of Alaska during the 1998 and 1999 navigation seasons was the third mildest and eighteenth mildest, respectively, in the Arctic Ocean for the 47 years from 1953 through 1999 (USDOC, NOAA, National Ice Center/USDOD, Navy, Naval Ice Center, 2000).

- The annual total of 180.64 survey hours for 1998 was the second highest for the MMS surveys (1987-1999), considerably higher than the mean of 130.63 hours (SD=36.47, n=13) for those same years.

- The 383 sightings for a total of 1,045 individual bowhead whales in Fall 1998 was the second-highest number for the 13 MMS project surveys (1987-1999), much higher than the 417 annual mean for whales (SD=455, n=13). As in 1997 (n=1,655), the high count in 1998 likely resulted from favorable open-water conditions along with the potential for some repeat counting between days of large aggregations of feeding and/or milling whales that appeared to remain in the same general area for several days.

- There were many feeding bowheads in 1997 and 1998 compared with other years (1987-1999). The many feeders in Fall 1997 were likely linked to a greater availability of prey species, possibly associated with a narrow band of warmer-than-average sea-surface temperatures (Treacy, 1998). Feeding bowheads in 1998 were observed within 20 nm of shore between 149°W. and 156°W. longitudes. On 19 September 1998, several large groups of bowhead whales were observed feeding near 71°10.0' N., between 154°31.0' W. and 155°21.8' W., further confirming the importance of the area east of Barrow as an occasional feeding area.

- In 1998, the first bowheads observed were on 31 August. Sighting rates were fairly level over the field season, with higher values on 18 September, 28 September, and 30 September. The data on daily relative abundance showed that the peak (mode) of the bowhead migration occurred on 19 September and the midpoint (median) occurred on 22 September. The last sighting of a bowhead in 1998 was made on 26 October.

- In 1999, the first bowheads observed were on 3 September. Sighting rates were fairly level over the field season, with higher values on 11 September, 16 September, and 21 October. The data on daily relative abundance showed that the midpoint of the bowhead migration occurred on 17 October and the peak occurred on 18 October. The last sighting of a bowhead in 1999 was made on 22 October.

- The relatively small median distances from shore and median water depths at bowhead sightings in Fall 1998 and 1999 in the West Region are consistent with a tendency for bowheads to migrate closer to shore and in shallower water during years of light general ice cover.

- The parametric ANOVA for distance from shore showed strongly significant differences among years in both regions.

- The parametric Tukey HSD test showed that in the East Region, bowhead whales in 1983 were migrating significantly farther offshore than in any other year except 1989. East Region whales in 1989 were significantly farther offshore, and in 1997 were significantly nearer to shore, than for most other years. In the West Region, bowheads in 1983, 1988, 1991, and 1992 migrated significantly farther offshore than for most other years. West Region whales in 1997 and 1998 migrated significantly nearer to shore than for many other years and were nearer to shore in 1998 than in other years (1982-1999). The mean for both East and West Region bowheads in 1998 was significantly nearer to shore than in 1999.

- The number of individual ringed seals sighted incidentally in Fall 1999 (n=1,325), was much higher than for any previous year (1982-1998).

- Other 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 (1979-1997) in the Beaufort Sea using similar survey methods (Ljungblad et al., 1987; Moore and Clarke, 1992; Treacy, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, and 1998).

VI. DISCUSSION

A. 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 airguns; 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.

From 24 July through 11 October 1998, Western Geophysical conducted open-water seismic in the central Alaskan Beaufort Sea using Ocean Bottom Cable (OBC). During winter-spring of 1998-1999, one over-ice seismic program was proposed for the offshore Beaufort Sea but was canceled. During summer 1999, there was one OBC 3-D marine-seismic program in the central Beaufort Sea. Only portions of the survey were completed due to the presence of sea ice early in the season and, after 1 September, a moratorium on seismic activity during ongoing whaling operations. During winter-spring of 1999-2000, two over-ice seismic programs proposed for the offshore Beaufort Sea area were canceled because of thick ice conditions and difficulties in implementing regulatory restrictions regarding ringed seals.

In general, 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 are visible from the vessel—as the bowhead whale migration progresses through the area of operations. For any explorations that occur during the fall, daily summaries of survey information are transferred from the field to Anchorage for use by MMS Resource Evaluation and by NMFS in implementing area-wide permit restrictions on high-energy seismic operations during the whale migration.

There were no drilling operations, with associated helicopter and vessel support, in the Beaufort Sea in 1998 or 1999. In general, during any fall drilling operations, daily summaries of field information from this survey, and other arctic surveys being conducted concurrently, are transferred by the MMS Team Leader to MMS Field Operations in Anchorage. The MMS and NMFS review 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 any drill sites.

The sighting data are typically used by 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. Project ice and weather data were also transmitted daily to the National/Naval Ice Center and National Weather Service for use in ground-truthing satellite imagery.

B. Management Use of Interannual Monitoring

The MMS bowhead whale monitoring began in 1979 and has continued every year up to the present. While some aspects of this study have been updated from time to time, the data recorded have remained remarkably parallel (especially data from 1982-1999), thus permitting many one-to-one comparisons between years. Such continuous, long-term, wide-area, aerial monitoring of a large whale migration is indeed unique.

In addition to the use of real-time information by both MMS and NMFS when documenting the progress of endangered bowhead whales past offshore drilling and seismic exploration operations (see Section VI.A. above), the project has been helpful to managers in other ways. Some notable examples are:

- providing raw data to all parties (MMS, Western Geophysical, NMFS, ARCO Alaska, Inc., and AEWC) at an Oil/Whalers Agreement Post Season Meeting on 18 December 1990 to determine whether the Fall 1990 bowhead migration had been temporarily blocked due to seismic exploration activities;
- providing all parties with annual reports from which data were subsequently cited in a declaration to a lawsuit in 1993 (AEWC et al. vs. Dr. Nancy Foster et al., Civil Action No. 93-1629 HHG) on the effects of Kuvlum drilling and seismic exploration operations on the bowhead migration corridor;

- providing upstream, offshore, and downstream sighting-and-effort data in order to enhance sample sizes of many site-specific studies looking at the potential effects of oil-industry activity on bowhead whale migrations;
- documenting geographic areas, especially migration corridors and feeding areas, used by whales on an annual basis. Such 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.

To support future management usages, we anticipate improving our monitoring program by:
- providing additional survey coverage in areas of marine industrial activity, potential feeding areas, and/or whaling concerns;
- focusing more on parametric analyses of distance from shore (for which we have a power analysis) than on nonparametric analyses of water depth;
- comparing migration timing of non-feeding bowheads past a small representative area;
- addressing the potential for autocorrelation on existing analyses;
- performing additional power analyses and making survey-effort adjustments as needed to detect smaller shifts in the migratory corridor;
- performing a fuller analysis of distance from shore and water depth at bowhead sightings relative to general ice cover;
- adding other analyses applicable to future management issues; and
- deleting analyses from the monitoring report that are expected to have limited future relevance.

The NMFS Administrator, Alaska Region, (letter dated 22 December 1998) commended MMS information support to NMFS: "The BWASP has provided a critical element in our ability to evaluate the effects of development in the Beaufort Sea on the bowhead whale. Additionally, the Minerals Management Service has demonstrated the flexibility and willingness to allow this program to compliment and extend project-specific monitoring required for authorizations under the Marine Mammal Protection Act (Incidental Harassment Authorizations). The combined information of these efforts has greatly extended our knowledge and facilitated conflict avoidance agreements. These agreements have allowed oil and gas activities to go forward while minimizing interference with traditional Native subsistence hunting. We have found BWASP statistical analysis and data presentation to be very useful in assessing potential impacts within the Beaufort Sea."

C. Conclusions

In 1998, day-to-day observations showed that many groups of bowhead whales appeared to pause for several days at various sites along the migration route while feeding. Other than these feeding bouts, we saw no indications that the migration was "stopped" in either 1998 or 1999, including areas near or just east of seismic 1998 exploration activities by Western Geophysical.

Oil industry studies, pooling our data with their own site-specific data, have detected localized deflections on the order of 10 to 20 km by bowhead whales in the immediate vicinity of certain types of active seismic exploration (USDOI, MMS, 1997b). Since preliminary power analysis of the ANOVA for distance of bowhead whales from shore (α=0.05, $\beta \leq 0.01$) showed minimum detectable differences of 7.8 km in the East Region and 9.7 km in the West (Treacy, 1998), we should be able to detect any region-wide 10- to 20-km shifts between years that may have derived from localized deflections. The Tukey HSD test of BWASP randomized bowhead sightings showed that the mean migration region-wide in Fall 1998 was significantly closer to shore in the both East and West Regions than in 1999, a year with no offshore seismic exploration or drilling activity during the fall season in the Alaskan Beaufort Sea.

To some extent, general ice cover, which includes shorefast ice, appears to influence the distance from shore and the water depth at which bowhead whales migrate. Insofar as 1998 was the third-mildest in the Arctic Ocean over the last 47 years, sea ice had little direct effect during that whale migration. However, the relatively small median distances from shore and small median water depths at bowhead sightings in both

regions in Fall 1998 are consistent with a tendency for bowheads to migrate closer to shore and in shallower water during years of light general ice cover.

D. Field Coordination and Information Support

During the field seasons, we coordinated with the Alaska Eskimo Whaling Commission (AEWC), Barrow, Alaska; the Western Geophysical site-specific aerial survey team; Whalers Communication Center, Deadhorse, Alaska; NMFS, Anchorage, Alaska; and NSB, Department of Wildlife Management, Barrow, Alaska. Accompanying the project and actively participating during Fall 1998 was Paul Stang, MMS Regional Supervisor, Leasing and Environment (Flight 21).

Selected BWASP information-support activities during calendar 1998 and/or 1999 included:

- providing data summaries to requesting agencies and private-sector organizations in support of:
  - (a) a draft Environmental Assessment for the Liberty Project,
  - (b) the final Environmental Impact Statement for Northstar;
  - (c) environmental sensitivity maps of the Beaufort Sea,
  - (d) State of Alaska "Proposed Oil and Gas Lease Sale: Beaufort Sea 1999",
  - (e) analysis of polar bear distribution by Fish and Wildlife Service, and
  - (f) MMS Leasing Activities Section relative to Sale 176.
- exchanging information with site-specific studies monitoring marine mammals in the presence of seismic activities in the central Alaskan Beaufort Sea, thereby increasing their sample size, especially in areas farther upstream, offshore, and downstream of seismic operations;
- presenting a paper on BWASP at the MMS Information Transfer Meeting, Anchorage, Alaska, on 19 January 1999 (http://www.mms.gov/omm/alaska/ess);
- participating in annual interagency evaluations (with NMFS, NSB, AEWC) on BP Exploration (Alaska)'s and Western Geophysical's site-specific planned and reported monitoring of marine mammals near seismic operations;
- contributing information on BWASP to a journal article on the Alaska Environmental Studies Program submitted to Arctic Research of the United States;
- providing data to and coordinating with scientists and subsistence whalers in support of the MMS study "Bowhead Whale Feeding in the Eastern Alaskan Beaufort Sea: Update of Scientific and Traditional Information";
- providing BWASP beluga whale sightings in support of the MMS study "Tagging and Satellite Tracking of Bowhead and Belukha Whales";
- providing BWASP 1992 data to Mr. Robert Schick, Duke University, as a basis for a Master's Thesis on spatial analysis of bowhead sightings relative to environmental factors;
- contributing information used in "The Year of the Ocean" and "Volunteers Monitor Endangered Bowhead Whales" in the December/January 1998 and October 1998 issues, respectively, of People, Land & Water;
- contributing text for "BWASP Team Involved in Rescue Mission" and "BWASP Flies Again", articles in MMS Today (Vol. 8, Number 1, Winter 1998);
- contributing information used in "MMS Dives into Better Whale Tracking", article in Federal Computer Week (4 May 1998; http://www.fcw.com);
- contributing information used on the MMS Alaska OCS Region Environmental Studies Section home page " (http://www.mms.gov/omm/alaska/ess); and
- contributing information used in a MMS Focus Sheet "Bowhead Whales and Oil-Industry Noise".

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