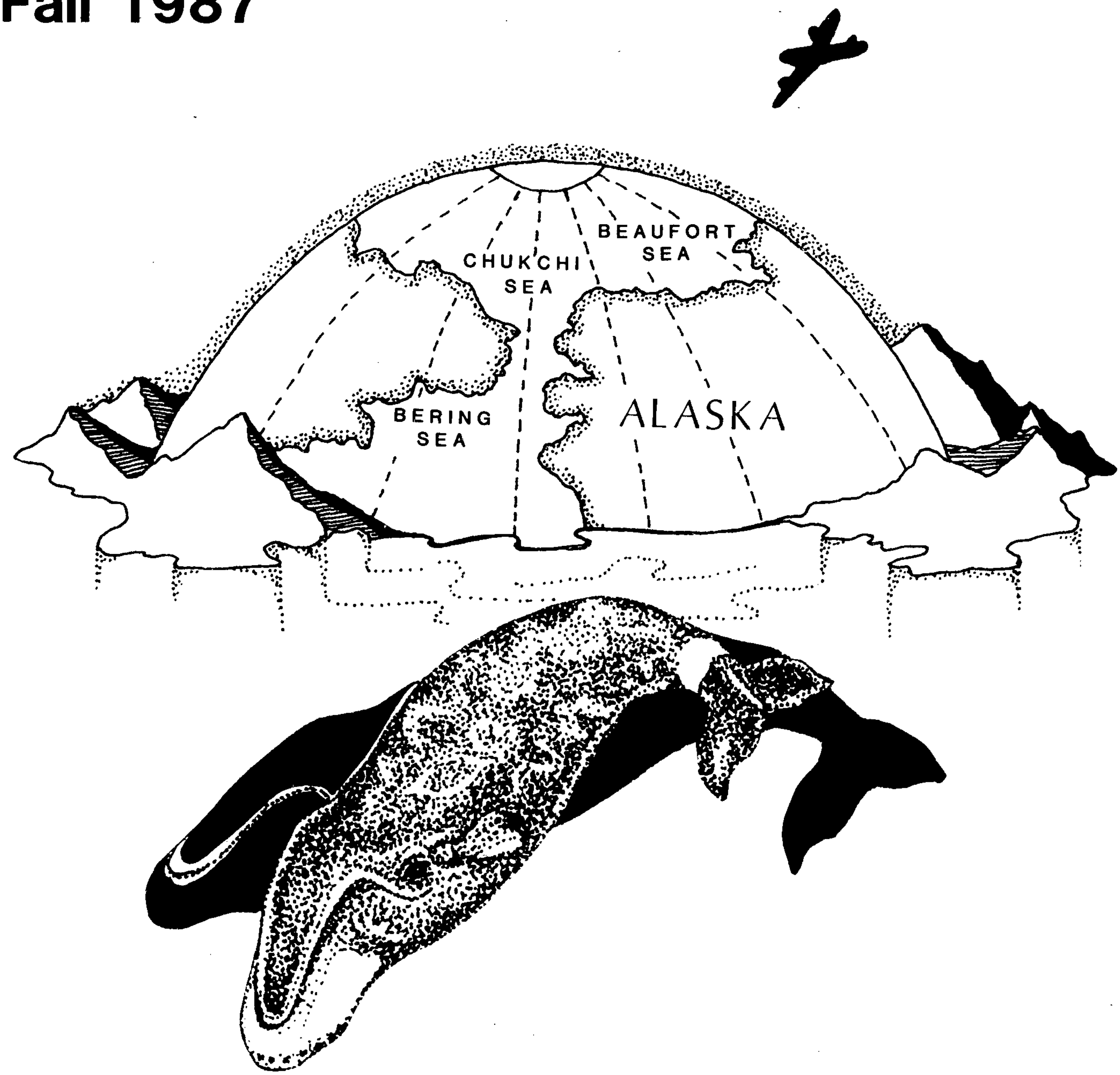
OCS Study
MMS 88-0030

Aerial Surveys of Endangered Whales in the Beaufort Sea, Fall 1987



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

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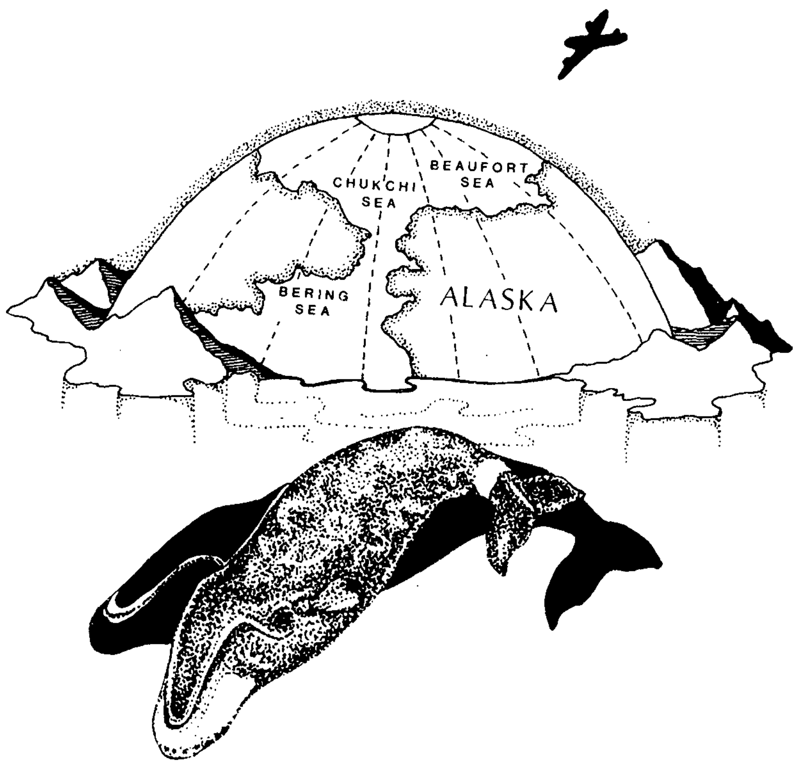
By Stephen D. Treacy, Project Manager
MMS Bowhead Whale Aerial Survey



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

Anchorage, Alaska
1988

ABSTRACT

This report describes field activities and data analyses for aerial surveys of bowhead whales conducted from 1 September 1987 to 31 October 1987 in the Beaufort Sea between 140°W. and 154°W. longitudes south of 72°N. latitude. A total of 110 bowhead whales, 150 beluga whales, 13 bearded seals, 285 ringed seals, and 58 unidentified pinnipeds were observed in 1987 during 149.34 hours of survey effort that included 63.20 hours on random transects. The initial sighting of bowhead whales in Alaskan waters occurred on 9 September 1987. Half of the 110 bowheads observed (median) had been counted by 29 September, while the peak count (mode) of 20 bowhead whales occurred on 7 October 1987. The last bowhead observed in the Beaufort Sea occurred on 30 October 1987 in open water (ice cover during September and October 1987 was exceptionally light). The median water depth of 31 meters for the migration corridor was consistent with data from most previous years.

ACKNOWLEDGMENTS

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CONTENTS

LIST OF FIGURES

LIST OF FIGURES
(Continued)

LIST OF TABLES

I. INTRODUCTION

A. Background

In 1953, the Outer Continental Shelf Lands Act (OCSLA) (43 U.S.C. 1331-1356) established Federal jurisdiction over the submerged lands of the continental shelf seaward of State boundaries. The Act charged the Secretary of the Interior with the responsibility for administering minerals exploration and development of the OCS. It also empowered the Secretary to formulate regulations so that the provisions of the Act might be met. The OCSLA Amendments of 1978 (43 U.S.C. 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 authorizes the Secretary of the Interior to 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 U.S.C. 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 U.S. Geological Survey (USGS) for supervising production. In 1982, the Minerals Management Service (MMS) assumed these responsibilities.

The National Environmental Policy Act of 1969 requires that all Federal Agencies use a systematic, interdisciplinary approach that will ensure the integrated use of the natural and social sciences in any planning and decisionmaking that may have an effect on the human environment. The MMS efforts in this direction include environmental impact statements (EIS's), environmental assessments, studies involving acquisition and analysis of marine-environmental data, literature surveys, socioeconomic-analysis studies, public conferences, and special studies (e.g., toxicity studies and spill-trajectory analyses, etc.).

The Marine Mammal Protection Act (MMPA) of 1972 (16 U.S.C. 1361-1407) recognized that certain species and populations of marine mammals are, or may be, in danger of extinction or depletion as a result of human activities and established a national policy that marine mammal populations should be protected and encouraged to develop to the greatest extent feasible, commensurate with sound policies of resource management. The Secretaries of the Departments of the Interior and Commerce are charged with all responsibility, authority, funding, and duties under the MMPA.

The Endangered Species Act (ESA) of 1973, as amended in 1978, 1982, and 1986, provides for the conservation of animal and plant species that have been determined to be endangered or threatened. The ESA requires that major Federal actions do not jeopardize the continued existence of listed species or result in the destruction or adverse modification of habitats determined to be critical. It also requires interagency consultation regarding potential jeopardy, alternatives to proposed actions, and information needs.

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 likely effects of the proposed Beaufort Sea Oil and Gas Lease Sale on the 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 is or is 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), and 97 (issued in 1987)--recommended continuing studies of whale distribution and OCS-industry effects on bowhead whales (USDOC, NOAA, NMFS, 1982, 1983, 1987). These opinions also requested monitoring of bowhead whale presence during periods when geophysical exploration and drilling may be occurring.

On 14 May 1982, the Secretary of the Interior imposed an approximately 2-month seasonal-drilling restriction on exploratory activity in the joint Federal/State Beaufort Sea sale area. 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 a monitoring plan for endangered whales that required aerial surveys. The Diapir Field Sale 87 Notice of Sale (1984) states that "Bowhead whales will be monitored by the Government, the lessee, or both to determine their locations relative to operational sites as they migrate through or adjacent to the sale area" (USDOI, MMS, 1984). The Beaufort Sea Sale 97 Notice of Sale (1988) does not contain a seasonal-drilling restriction but states that "MMS intends to continue its areawide endangered whale monitoring program in the Beaufort Sea during exploration activities. The program will gather information on whale distribution and abundance patterns and will provide additional assistance to determine the extent, if any, of adverse effects to the species" (USDOI, MMS, 1988).

The current 5-Year OCS Oil and Gas Leasing Program schedule indicates that additional lease sales are planned for the Beaufort and Chukchi Seas. Information from the continuing endangered whale monitoring program will be used to prepare draft and final EIS's for these sales. Baseline information will be used to write postlease EIS's for development and production in offshore arctic waters. Such information also will be integral to documents related to the ESA Section 7 consultation.

Between 1979 and 1987, MMS funded year-to-year 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 these whales was approved by the Associate Director for Offshore Minerals Management. A concurrent study of endangered whales in the Chukchi Sea (Ljungblad et al., 1988) also was funded by MMS. Both the present study in the Beaufort Sea and the study in the Chukchi Sea employed identical aerial-survey and data-analysis methodology based directly on methods descriptions found in Ljungblad et al. (1987) and should be considered together to obtain a more complete understanding of the Fall 1987 movements and distribution of whales in arctic waters. The MMS will continue to use MMS personnel to perform fieldwork and reporting activities on an annual basis.

To assure consistency with earlier surveys, personnel from NOSC and SEACO, Inc., actively participated in the training of project observers. Technical training prior to the field season included lectures, slide presentations, simulated data-collection and field-analysis workshops with the onboard computer system, and aerial surveys of beluga whales in Cook Inlet. Previous observers conducted additional onboard training in established methodology for each project team and periodic consistency checks of the collected data during 1987 Beaufort Sea surveys. Following the field season, the contractor for the previous bowhead surveys performed computerized checks and analyses of the raw data using the same computer programs developed for those earlier surveys.

B. Goals

The present goals of the ongoing endangered whale-survey program are to:

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

2. Provide real-time, site-specific data on endangered whales for use by MMS Resource Evaluation in day-to-day regulation of seismic-exploration operations;

3. Continue collection of data to describe temporal and spatial trends in the distribution, relative abundance, habitat, and behaviors of endangered whales in arctic waters;

4. Continue data collection and between-year trend analysis of the median depth (or distance from shore) of the migration axis for bowhead whales;

5. Record and map nonendangered marine mammals observed incidentally to endangered whale surveys; and

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

II. METHODS AND MATERIALS

A. Study Area

The overall annual survey program is based on a design of random field transects within established geographic blocks in and adjacent to Chukchi and Beaufort Sea sale areas offshore Alaska. The present study, which was focused on the bowhead whale migration from 1 September 1987 to 31 October 1987, included Beaufort Sea Survey Blocks 1 through 11 (Fig. 1) between 140°W. and 154°W. longitude south of 72°N. latitude. Occasional flights involved survey coverage in Canada as far east as 137°W. longitude.

II

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 4 meters (m) thick, on average, 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, where mean annual temperature is about -12°C. Precipitation ranges from 13 centimeters (cm) at Barrow to 18 cm at Barter Island and occurs mostly as summer rain. Fog frequently reduces visibility along the coast during the open-water season. Winds are persistent in direction and speed. Mean annual speed is 5 m per second at Barrow and 6 m per second at Barter Island. Sea breezes occur during about 25 percent of the summer and extend to at least 20 km offshore (Brower et al., 1977).

Sea state is another environmental factor affecting visibility during aerial surveys. Ocean waves, which are generally from the northeast and east, are limited to the open-water season, during which 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 in summer. Wave heights greater than 0.5 m occur only in 22 percent of the observations summarized by Brower et al. (1977). Wave heights greater than 5.5 m are not reported within this Beaufort Sea database of 2,570 observations.

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

B. Equipment

The two aircraft used for the surveys were a Grumman Turbo Goose Model G21G with call sign N780 and a de Havilland Twin Otter Series 300 with call sign 302EH. Both aircraft were equipped with a Global Navigation System (GNS) 500

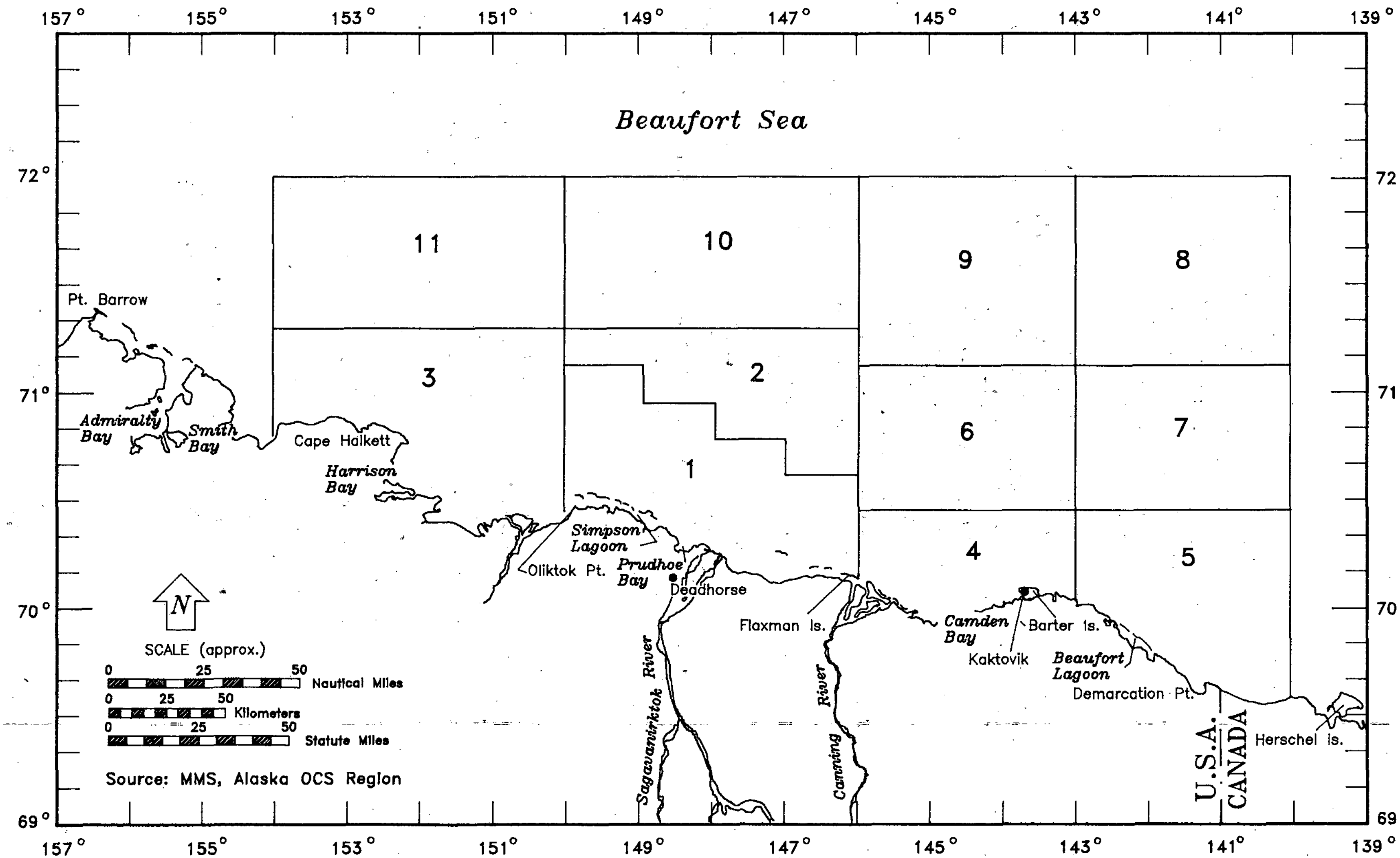


Figure 1. Fall 1987 Study Area Showing Survey Blocks (transect surveys were performed in Blocks 1–7 and 11)

that provided continuous position updating (0.6-km/survey-hour [h] precision) and transect-turning-point programming. The Grumman's maximum time aloft was approximately 7.5 hours, and the Twin Otter's was 4.5 hours extended to 7.5 hours through the use of a supplemental onboard fuel tank.

The Grumman Goose cockpit was outfitted with four seats, each of which afforded excellent visibility through large side windows for the two principal observers and the pilots. A long, rectangular window behind the cockpit provided good visibility for the observer-recorder. The Twin Otter was equipped with small bubble windows aft for an observer and an observer-recorder. A third observer-navigator occupied the copilot seat and was afforded good forward and side viewing from that position. Each observer had a clinometer to take angles on endangered whale sightings. Observers and pilots were linked to common communication systems, and commentary on both aircraft could be recorded.

A portable (Hewlett-Packard 85) computing system was used aboard both aircraft to store and later to analyze flight data. The computer was interfaced to the GNS for automatic input of entry number, time, latitude, and longitude and to the radar altimeter for precise input of altitude.

C. Aerial-Survey Design

The 1987 field schedule was designed to monitor the progress of the bowhead migration across the Alaskan Beaufort Sea from September through October. Particular emphasis was placed on regional surveys to assess fine-scale shifts in the migration pathway of bowhead whales in this area. Additional monitoring entailed the priority coordination and data management necessary to support seasonal offshore-drilling regulations.

Daily flight patterns were based on sets of unique transect grids produced for each survey block. Transect grids were derived by dividing each survey block into sections 30 minutes of longitude across. One of the minute marks along the northern edge of each section was selected at random to designate one end of a transect leg. The other endpoint of the transect leg was determined similarly using a separate randomly generated number along the southern edge of the same section. A straight line, representing one transect leg, was drawn between the two points. The same procedure was followed for all sections of the survey block. Transect legs were then connected alternately at their northernmost or southernmost ends to produce one continuous flight grid within each survey block.

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

Transect lines were generated in random fashion both at their point of origin and at their termination point within 30-minute sections of longitude (see above). The use of random-transect grids is a requirement for later analyses of median water depths at bowhead sightings based on line-transect theory (Cochran, 1963) and analyses of absolute densities based on strip-transect theory (Estes and Gilbert, 1978).

Nonrandom surveys were flown to further identify whales and their behaviors off the transect line, or when in transit to a transect block, transect line, or a new base of operations. These surveys did not follow a preset paradigm; but data from nonrandom surveys were considered combinable with random-transect data to obtain overall distribution patterns, relative abundance, and behavior of whales and other marine mammals.

Aerial surveys in the Beaufort Sea were flown in the de Havilland Twin Otter (302EH) based out of Deadhorse, Alaska, from 1 September to 15 October 1987, with MMS scientists. Additional aerial surveys in the Beaufort Sea (and Chukchi Sea) were flown in the modified Grumman Goose (N780) with scientists from SEACO, Inc., from 1 September to 31 October 1987.

D. Survey-Flight Procedures

During a typical flight (Fig. 2), a search leg was flown to the survey block, followed by a series of random-transect legs joined together by connect legs, with search legs conducted back to the base of operations. Surveys generally were flown at a target altitude of 458 m. This higher altitude was maintained, when weather permitted, in order to maximize visibility and minimize potential disturbance to marine mammals. The target survey speed was 230 km per hour (km/h) for the Twin Otter.

Random-transect surveys were flown whenever feasible, using a clinometer to measure the angle of inclination to each initial sighting of endangered whales when the sighting location (or whale-dive site) was abeam of the aircraft.

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

E. Data Entry

One of four different data-entry formats was selected on the computer, depending on the reason for entry. Whenever possible, a 28-key entry format was used when whales were seen (Table 1). An abbreviated 20-key sighting-update format was used when several whales were sighted within a short period of time. An even shorter rapid-sighting update (9-key format) was used in areas of extremely high animal concentrations to avoid any lumping of sightings. A position-update, 13-key format including data on weather, visibility, ice cover, and sea state was entered at turning points, when

Table 1

Data-Entry Sequence on the Portable Flight Computer

Sequence	Rapid Sighting Update (9-Key)	Position/Environmental Update (13-Key)	Sighting Update (20-Key)
1. Entry number	X	X	X
2. Time	X	X	X
3. Latitude	X	X	X
4. Longitude	X	X	X
5. Altitude	X	X	X
6. Reason for entry	X	X	X
7. Survey type (flag)	X	X	X
8. Weather		X	
9. Visibility right		X	
10. Visibility left		X	
11. Ice coverage		X	
12. Ice type		X	
13. Sea state		X	
14. Water color			
15. Water depth			
16. Species	X		X
17. Clinometer angle			X
18. Sighting cue			X
19. Behavior			X
20. Total number	X		X
21. Estimated size class			X
22. Total number calves			X
23. Swim direction			X
24. Estimated swim-speed class			X
25. Response to aircraft			X
26. Repeat sighting			X
27. Photo roll number			X
28. Photo frame numbers			X

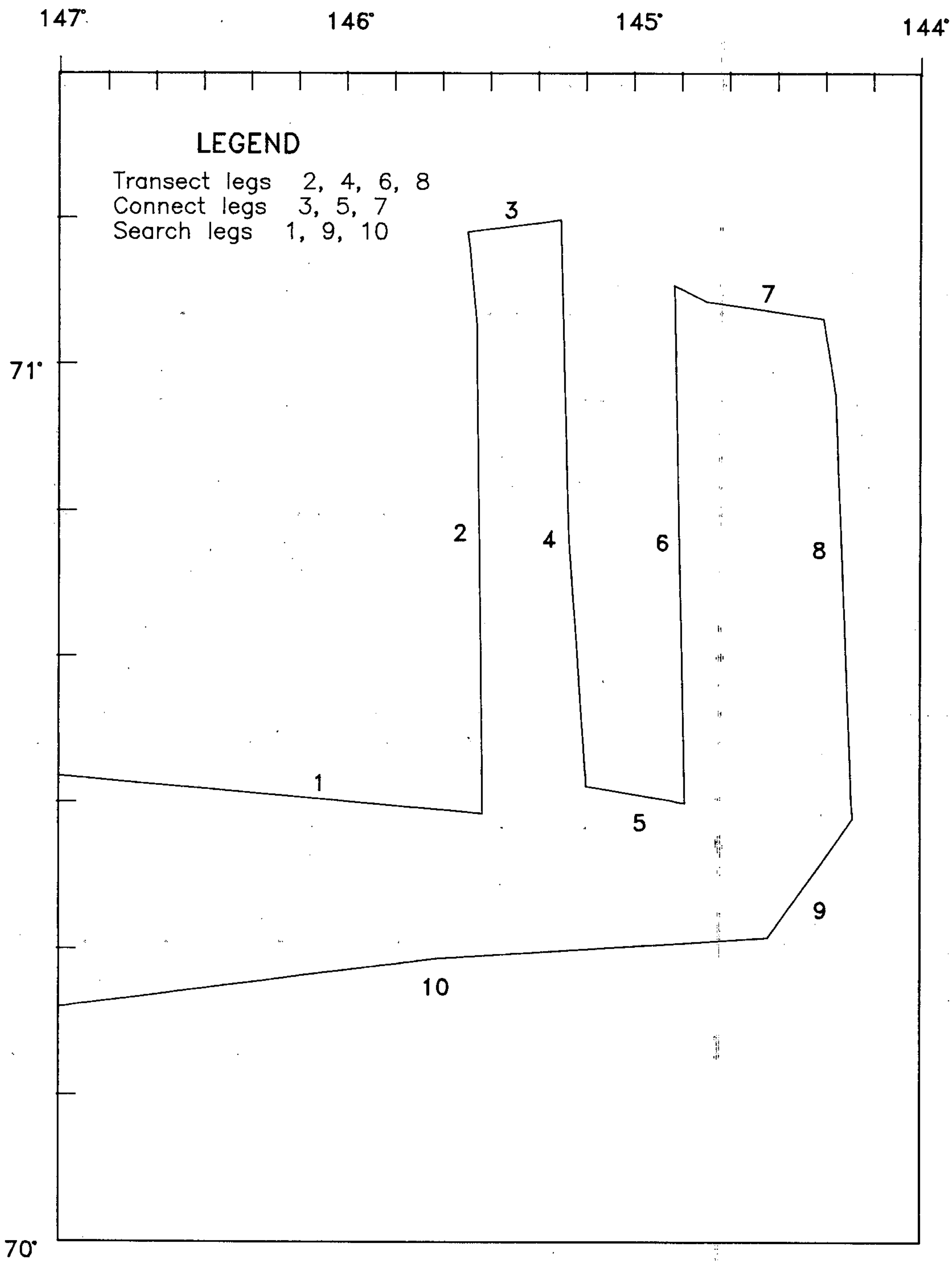


Figure 2. Example of Computer–Generated Flight Track

changes in environmental conditions were observed, and otherwise at 10-minute intervals. All entries were coded to reflect the type of survey being conducted (Table 1: No. 7).

For the purpose of discussion behaviors were cataloged into three types: (1) locomotive behaviors, including swimming and diving; (2) physiological behaviors such as milling, feeding, mating, cow/calf association, and resting; and (3) display behaviors, including breaches, spy-hops, tail- and flipper-slaps, rolls, and underwater blows (Table 2). Swimming speed was subjectively estimated by observing the time it took a whale to swim one body length. An observed swimming rate of one body length per minute corresponded to an estimated speed of 1 km/h; one body length per 30 seconds was estimated at 2 km/h, and so on. Swimming speed and whale size were recorded by relative category (i.e., still, 0 km/h; slow, 0-2 km/h; medium, 2-4 km/h; or fast, >4 km/h; and calf, immature, adult, or large adult, respectively) rather than on an absolute scale.

In compliance with Condition B.4-6 of NMFS Permit No. 459, to "take" endangered marine mammals, any sudden overt change in whale behavior observed coincidentally with the arrival of the survey aircraft was recorded (and later reported) as "response to aircraft," although it was impossible to determine the specific stimulus for the behavioral change. Such changes included abrupt dives, sudden course diversion, or cessation of behavior ongoing at first sighting.

Sea state was recorded according to the Beaufort scale outline in Piloting, Seamanship, and Small Boat Handling (Chapman, 1971). Ice type was identified using terminology presented in Naval Hydrographic Office Publication Number 609 (U.S. Navy, 1956), and ice cover was estimated in percent.

F. General Data Analyses

Ice concentrations in the Beaufort Sea were analyzed every seventh day from 8 September through 27 October 1987. Graphics were digitized from the NOAA/U.S. Navy Joint Ice Center Southern Ice Limit charts into categories of zero to 25-percent, 26- to 50-percent, 51- to 75-percent, and 76- to 100-percent ice cover.

Observed bowhead distribution was plotted semimonthly in relation to OCS oil and gas lease-sale areas within the Beaufort Sea study area. An index of relative abundance was derived as whales per unit effort (WPUE = number of whales counted/h of survey effort) per survey block for bowheads and belugas.

The timing of the 1987 bowhead migration through the study area was analyzed as sightings per unit effort (SPUE = number of sightings counted/h of survey effort) and WPUE per date. Habitat preference was depicted as percentage of whales per ice class and percentage of whales per depth regime. Directionality of whale headings was analyzed using Rayleigh's test (Batschelet, 1972). Additional statistical comparisons, correlations, and regressions were performed, as appropriate (Zar, 1984).

All whale sightings were entered into the distribution and relative-abundance analyses, regardless of the type of survey leg being conducted when the

Table 2

Operational Definitions of Observed Bowhead Whale Behaviors

LOCOMOTIVE:	
Swimming	Whale(s) proceeding forward through the water propelled by tail pushes.
Diving	Whale(s) changing swim direction or body orientation relative to the water surface resulting in submergence; may or may not be accompanied by lifting the tail out of the water.
PHYSIOLOGICAL:	
Milling	Whale(s) swimming slowly at the surface in close proximity (within 100 m) to other whales.
Feeding	Whale/whales 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 whales, or as surface swimming with mouth agape.
Mating	Ventral-ventral orienting of two whales, often with one or more other whales present to stabilize the mating pair. Mating is often seen within a group of milling whales. Pairs may appear to hold each other with their pectoral flippers and may entwine their tails.
Cow-Calf	Calf nursing; calf swimming within 20 m of an adult.
Resting	Whale(s) floating at the surface with head, or head and back exposed, showing no movement; more commonly observed in heavy-ice conditions than in open water.
DISPLAY:	
Rolling	Whale(s) rotating on longitudinal axis, sometimes associated with mating.
Flipper-Slapping	Whale(s) floating on side, striking the water surface with pectoral flipper one or many times; usually seen within groups or when the slapping whale is touching another whale.
Tail-Slapping	Whale(s) floating horizontally or head-downward in the water waving tail back and forth above the water and striking the water surface; usually seen in group situations.

Table 2

Operational Definitions of Observed Bowhead Whale Behaviors
(Continued)

Spy-Hopping	Whale(s) extending head vertically out of the water such that up to one-third of the body, including the eye, is above the surface.
Breaching	Whale(s) launching upwards such that half to nearly all of the body is above the surface before falling back into the water, usually on its side, creating an obvious splash.
Underwater Blow	Whale(s) exhaling while submerged, thus creating a visible bubble.

sighting was made. Therefore, distribution scattergrams and WPUE represent the total sighting database in relation to the total survey effort.

Sightings of beluga whales, ringed and bearded seals, and other marine mammals are depicted on separate maps.

Density estimates were based on strip-transect-analyses methods (Estes and Gilbert, 1978). Distance from the transect line was calculated trigonometrically from the altitude of the survey plane at the time of sighting and the clinometer angle recorded for each initial sighting location. Only endangered whale sightings within 1 km of random-transect legs were used to derive density estimates, since the number of sightings decreases markedly at greater distances from the trackline (Moore, oral comm., 1988). If no sightings were made on random transects within a survey area, that density was not calculated. In addition to the survey-block analysis, density estimates were derived for bathymetrically stratified subregions in the Beaufort Sea Planning Area and are presented, with a description of density-estimate methodologies, in Appendix A.

The general water depth at each bowhead sighting in the 1982-1987 database was derived using the computer program DEPTH, which assigned a metric depth value averaged over an area 5 nautical miles (nmi) of latitude by 20 nmi of longitude (approximately 9.25 km by 37 km) in the Beaufort Sea, between 141°W. and 157°W. longitudes south of 72°N. latitude. This scaling assigns depth to sighting locations with an accuracy of approximately ±3.5 m over most of the study area. At the shelf break between 100 m and 1,000 m in Regions B and C, the accuracy was approximately ±20 m. Values assigned to each segment were subjectively averaged from depths read off of NOAA Provisional Chart 16004 when the DEPTH software was written.

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

The analysis protocol specifying the use of median water depth to detect interannual shifts in the bowhead migration route is 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) and is incorporated by reference from Ljungblad et al. (1987).

The null hypotheses tested via median-depth analysis were prescribed in Houghton, Segar, and Zeh (1984) as:

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

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

Because of the bathymetry of the Alaskan Beaufort Sea, a seaward displacement of the fall-migration route would be represented, via this analysis, as a shift to a deeper median depth.

To assess possible fine-scale shifts in the 1987 migration axis over the known fall-migration corridor, the median depth, 99-percent confidence interval (CI), and overall depth range were calculated for Regions B, C', and D' of the study area (Fig. 3). All bowhead sightings made while on random line transects were included in the median-water-depth analyses.

Region B falls between 150°W. and 153°30'W. longitudes and south of 72°N. latitude. Region C' falls between 146°W. and 150°W. longitudes south of 71°20'N. latitude. Region D' falls between 141°W. and 146°W. longitudes and extends south of 71°10'N. latitude.

The bowhead-sighting database was sorted such that only sightings made on random-transect lines were stored onto a separate data file (MEDEPTH1). The MEDEPTH1 data file was sorted such that only bowhead sightings made on random transects in September and October were stored (MEDEPTH2). To increase the resolution of depths assigned to bowheads sighted on random-transect lines, each of these sightings was plotted by hand and compared visually against NOAA Provisional Chart 16004.

The MEDEPTH2 depth values were then ranked from lowest to highest values; and a sample median, 99-percent CI's, and overall sample range were tabulated. The 99-percent CI was defined as

$$\begin{aligned} L_1 &= X_{C+1} : \text{lower limit} \\ L_2 &= X_{n-C} : \text{upper limit} \end{aligned} \qquad (1)$$

Where $\alpha(2) = 0.01$, C is determined from a table of critical values (Zar, 1984: Table B-26) when sample size $n \geq 8$. The CI's were calculated at the 1-percent level to reduce the probability of incorrectly asserting that a change in migration route had occurred based on comparing any one year to six others. For example, the probability of incorrectly determining a change occurred based on one of five tests is approximately 23 percent, if tested at the 5-percent level, but only about 5 percent if tested at the 1-percent level (Houghton, Segar, and Zeh, 1984).

The Mann-Whitney U test was then used to address the question of potential shifts in the axis of the bowhead whale fall-migration route. The Mann-Whitney test is a nonparametric procedure performed on ranked samples where U and U' are calculated as:

$$\begin{aligned} U &= n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1 \\ U' &= n_1 n_2 - U \end{aligned} \qquad (2)$$

where, n_1 = the smaller of the two samples being compared, if sample sizes are unequal
n_2 = the second sample set
R_1 = sum of the ranks of the n_1 sample

If either U or U' is as great or greater than the tabularized critical value at the chosen level of significance, the difference between the samples is significant. If the size of the smaller sample exceeds 20 or the size of the larger sample exceeds 40, the distribution of U approaches the normal distri-

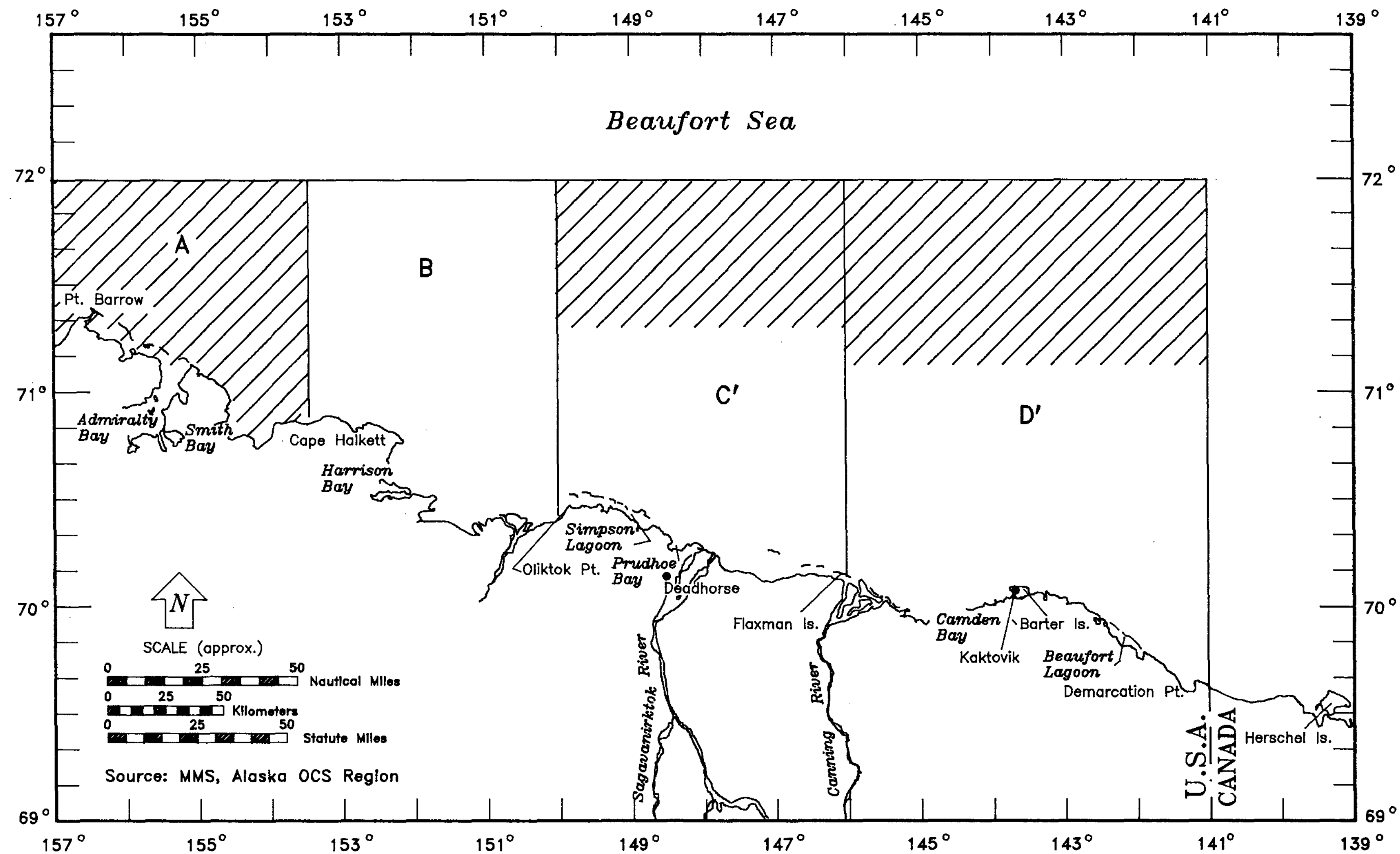


Figure 3. Regions B, C', and D' (used in 1987 and interyear analysis of median water depths at random bowhead sightings)

bution and a Z value is compared to the critical value t_α, where Z is calculated as:

$$Z = \frac{|U - \mu U| - 0.5}{\sigma U} \qquad (3)$$

after μU and σU have been derived from the sample sizes as

$$\mu U = \frac{n_1\ n_2}{2} \quad ; \quad \sigma U = \sqrt{\frac{n_1\ n_2\ (N+1)}{12}} \qquad (4)$$

A series of Mann-Whitney paired comparisons were made on annual depth values derived from the MEDEPTH2 data file, with each year compared to all others such that annual and/or overall shifts in migration route over the 1979-1986 study period could be evaluated. Subsequently, the MEDEPTH2 file was sorted by region (B, C', and D'); and a series of paired comparisons were calculated for each region such that annual variations or potential shifts in median depth could be assessed for these smaller areas.

III. RESULTS

A. Environmental Conditions

Overall, partly cloudy to overcast skies were the norm during September and October 1987. Visibility was generally unlimited, with some short periods of zero visibility. Ice conditions in the Beaufort Sea were very light during the survey period, with large expanses of open water available to migrating whales (Figs. 4 through 11).

During the first half of September, there were 11 days when weather permitted flight attempts. The weather during these flight days was generally good, including many days with clear skies. Sea states averaged Beaufort 2 to 4, with one flight (13 September) aborted within the first hour due to Beaufort 6 seas. Some periods of zero visibility of whales due to low clouds were recorded on 6, 8, 12, and 15 September. No ice was encountered on flights from 2 to 8 September, with broken floe ice (15-25%) seen from 9 to 13 September. Floe ice (50-85%) was noted from 14 to 15 September north of 70°40'N. latitude between 144°30'W. and 147°30'W. longitudes.

During the last half of September, there were 11 days when weather permitted flight attempts. Occasional fog was encountered from 15 to 26 September, with notable precipitation on 18, 28, and 30 September. Sea states averaged Beaufort 2 to 4 throughout, except for day-long, calm seas (Beaufort 1) on 29 September. Two short flights (<1 h) were aborted due to higher sea states (Beaufort 5 to 6) on 18 September and 21 September. Another short flight on 16 September was aborted due to fog and low ceilings.

Periodic zero visibility of whales due to low clouds was recorded on 16, 18, and 20 September, with reduced visibility due to glare noted from 29 to 30 September. Little or no sea ice was encountered except for 80-percent broken floe and/or grease ice on 17 September north of 71°N. latitude between 144°20'W. and 145°50'W. longitudes.

During the first half of October, there were 11 days when weather permitted flight attempts. There were alternating periods of fog and clear skies throughout these flights. Sea states generally were low (Beaufort 1 to 2) from 5 to 10 October, increasing to Beaufort 2 to 4 through 15 October. Some high sea states (Beaufort 5 to 6) were noted on 1, 5, and 14 October, with very high sea states (Beaufort 7 to 8) recorded on 11 October. Day-long calm seas (Beaufort 1) were noted on 7 and 9 October. Periodic zero visibility of whales due to low clouds was recorded initially (on 1, 6, and 7 October) and again on 15 October. Surface glare was a recurrent visibilityreduction factor from 5 to 15 October. New or grease ice was encountered on all flight days, often with localized concentrations up to 100 percent between 143°W. and 154°W. longitudes. Landfast ice was noted daily from 8 to 15 October (Fig. 9).

During the last half of October, there were 8 days during which survey flights were made. Survey coverage in the Beaufort Sea was very light from 16 to 24 October, with only three short (<1 h) overflights on 19, 21, and 23 October that extended east of 154°W. longitude into the study area. During the 5 flight days between 25 and 31 October that were dedicated to the study area, conditions varied from excellent, with unlimited visibility and low sea states

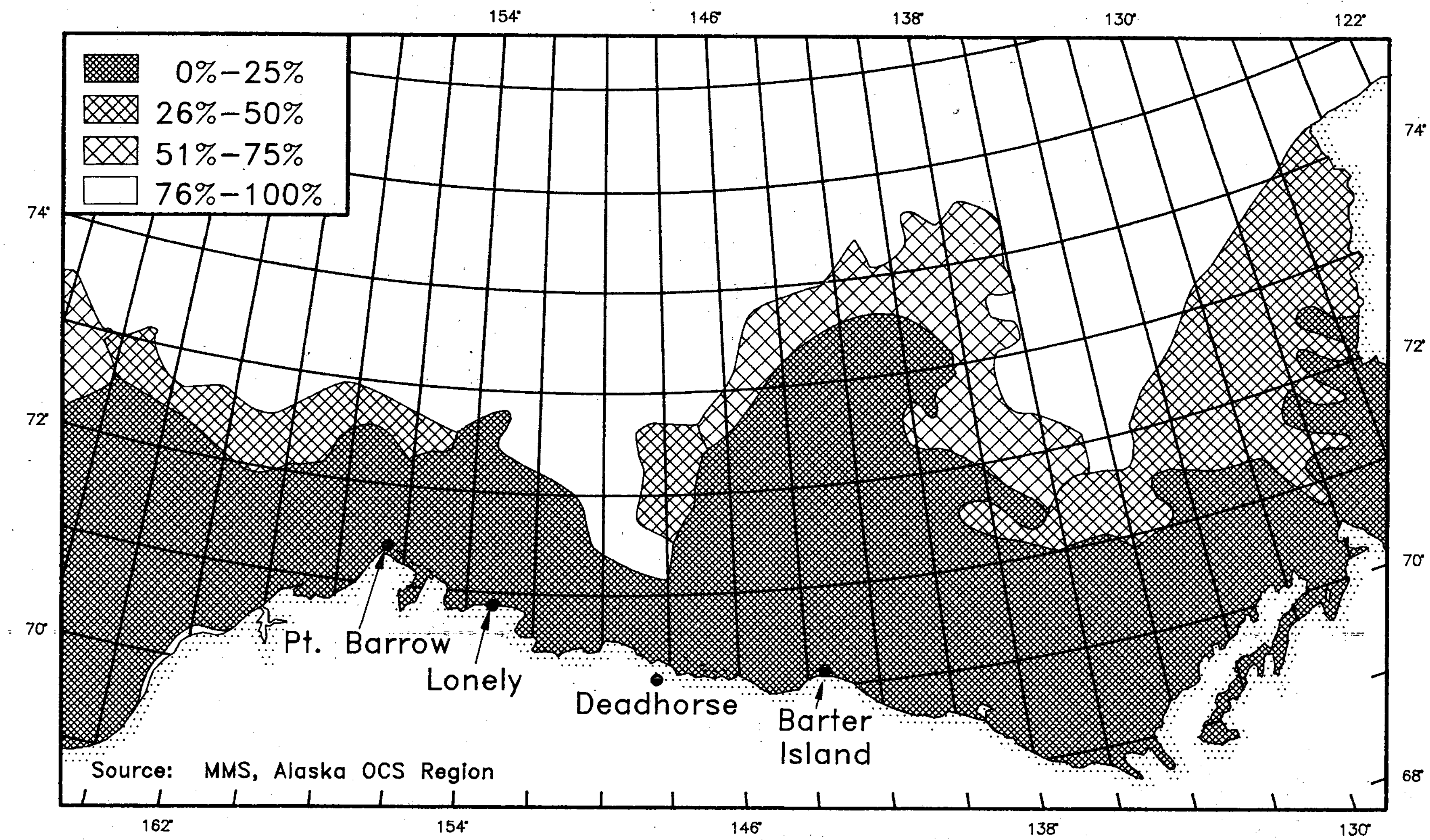


Figure 4. Map of Ice Concentrations in the Beaufort Sea, 8 September 1987

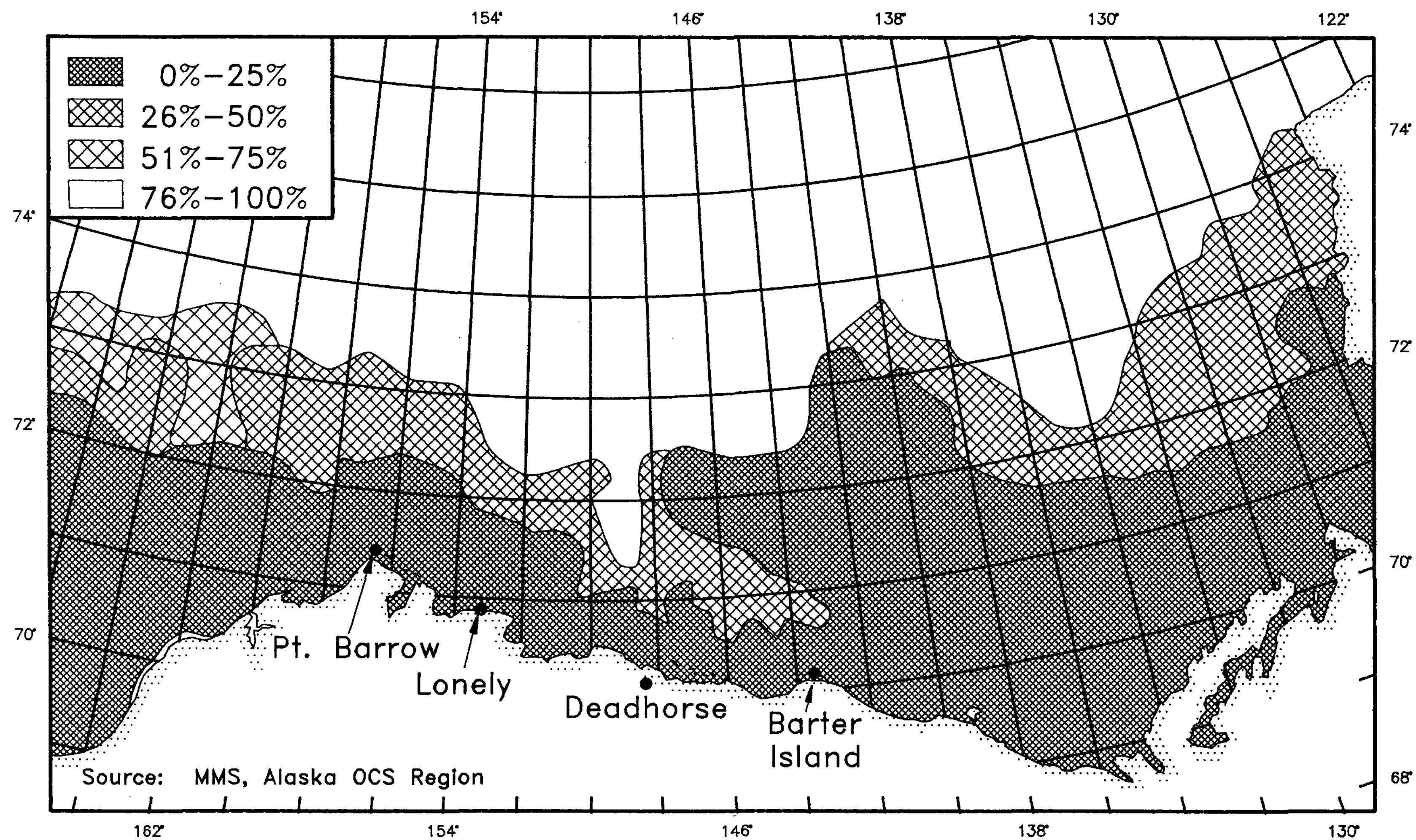


Figure 5. Map of Ice Concentrations in the Beaufort Sea, 15 September 1987

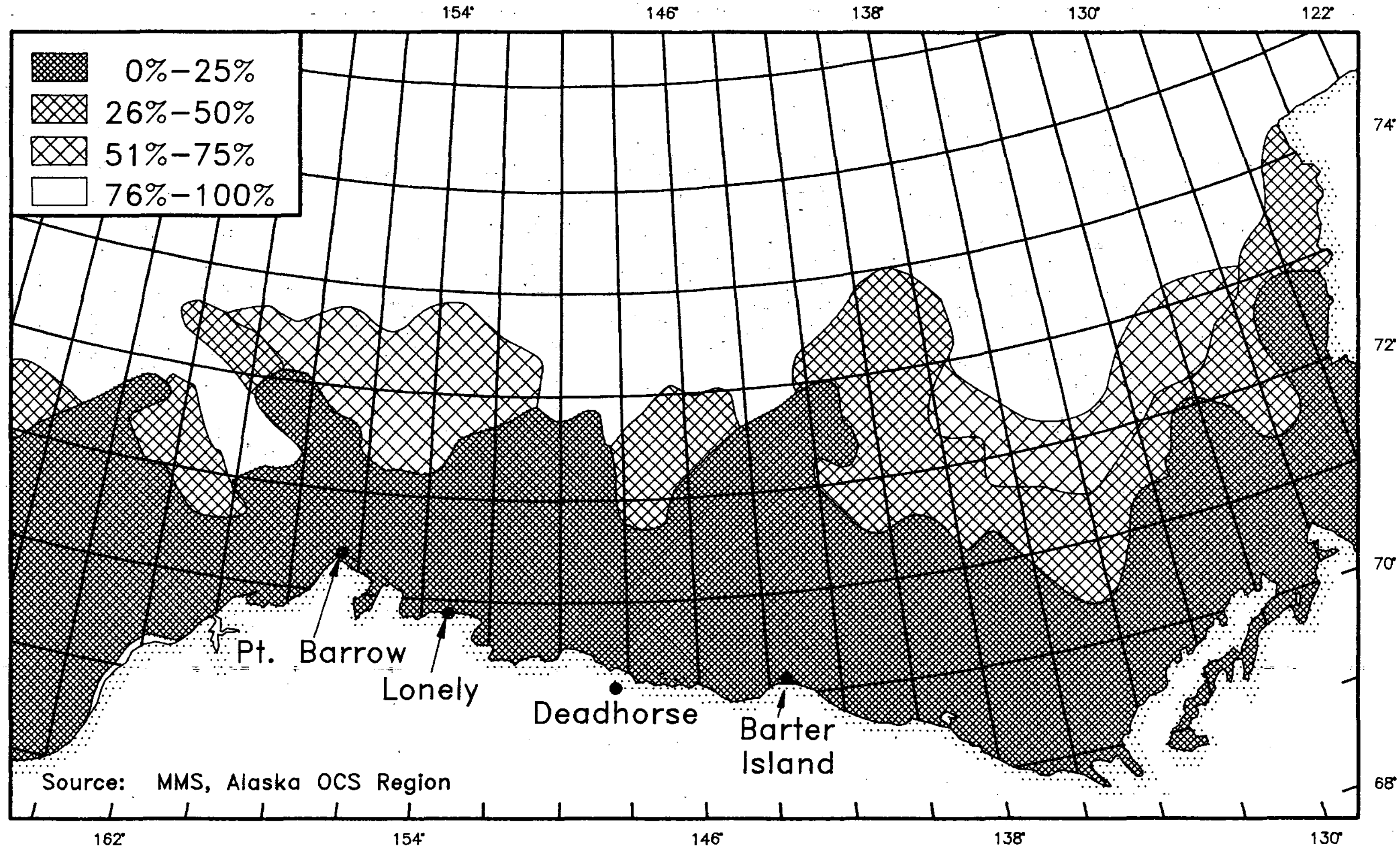


Figure 6. Map of Ice Concentrations in the Beaufort Sea, 22 September 1987

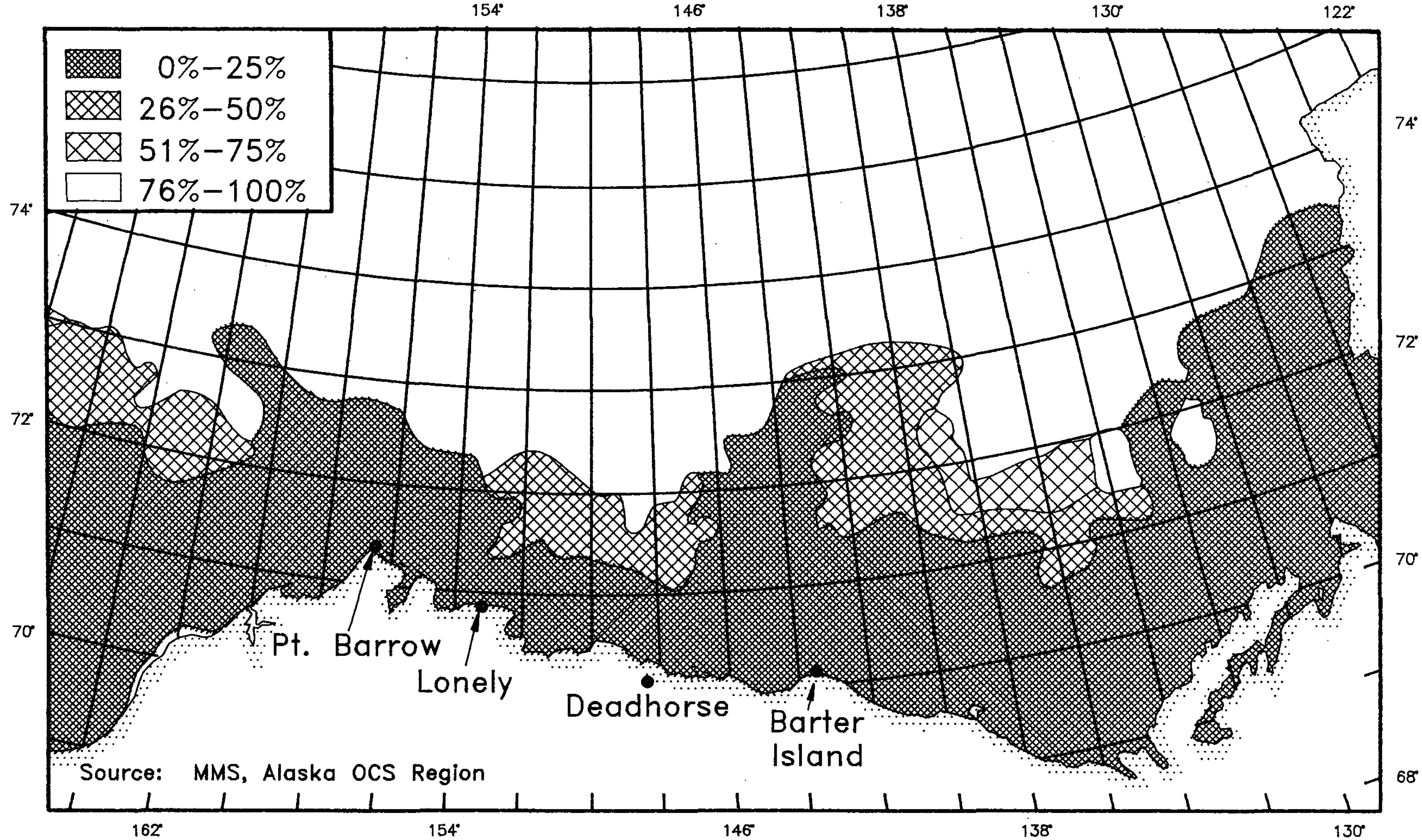


Figure 7. Map of Ice Concentrations in the Beaufort Sea, 29 September 1987

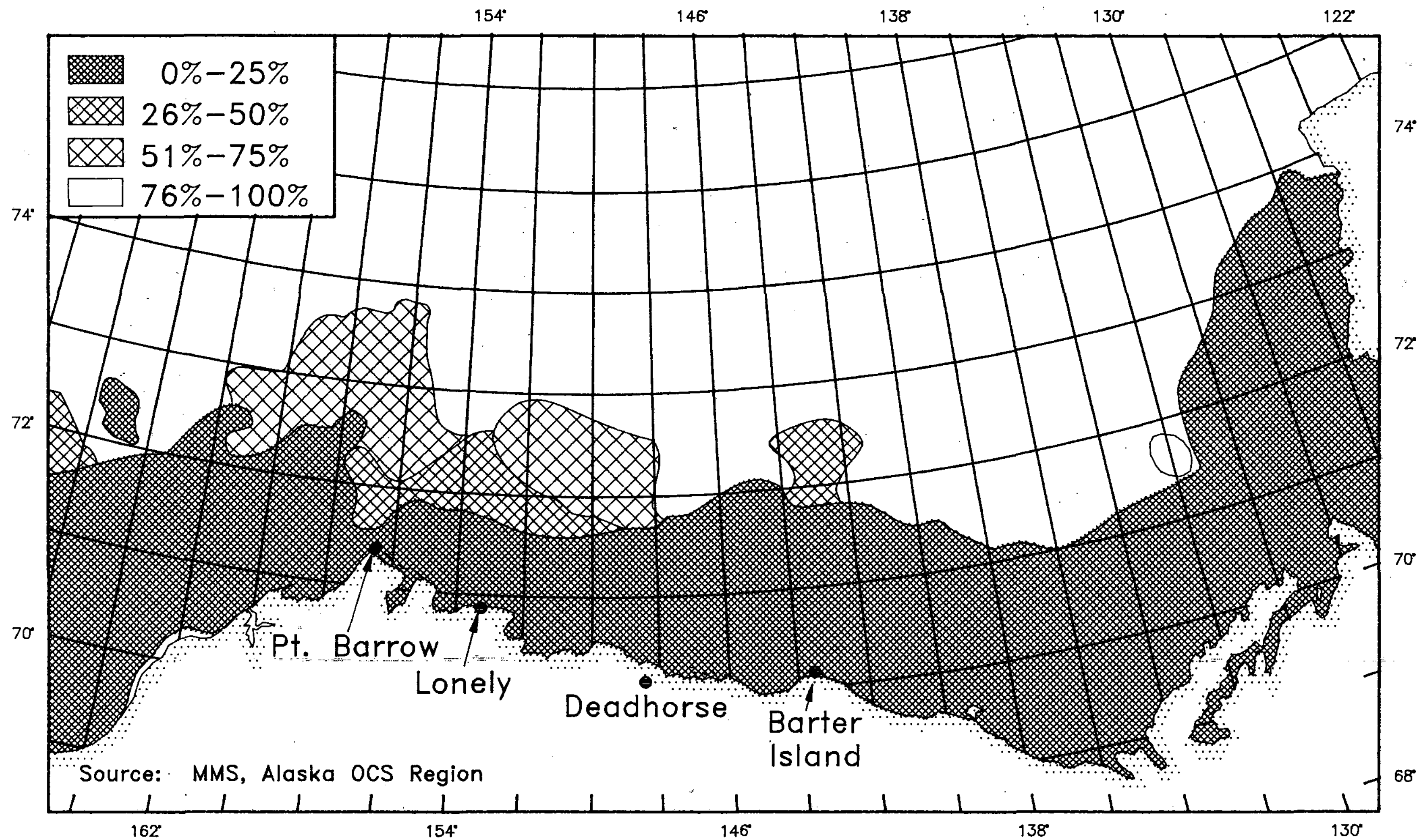


Figure 8. Map of Ice Concentrations in the Beaufort Sea, 6 October 1987

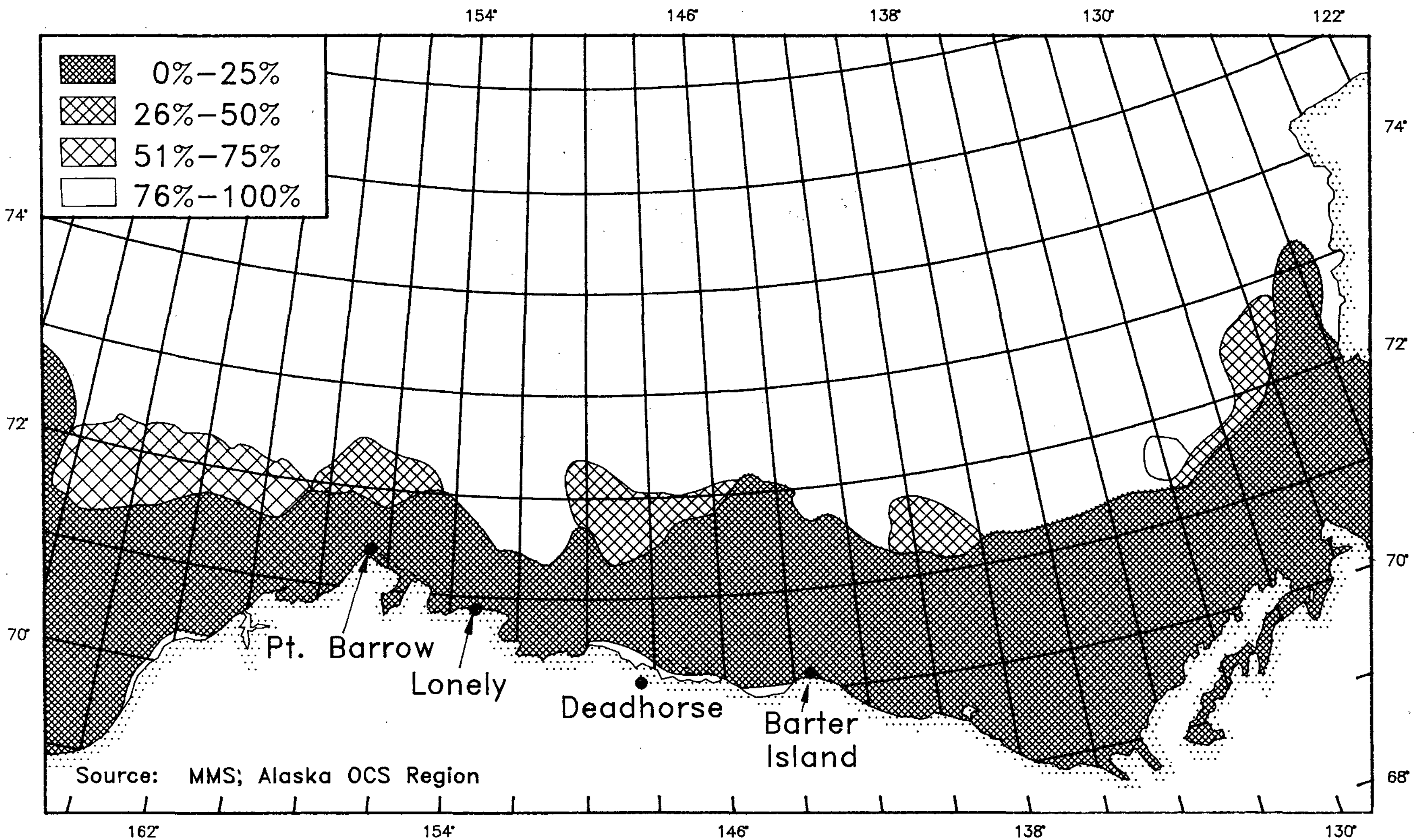


Figure 9. Map of Ice Concentrations in the Beaufort Sea, 13 October 1987

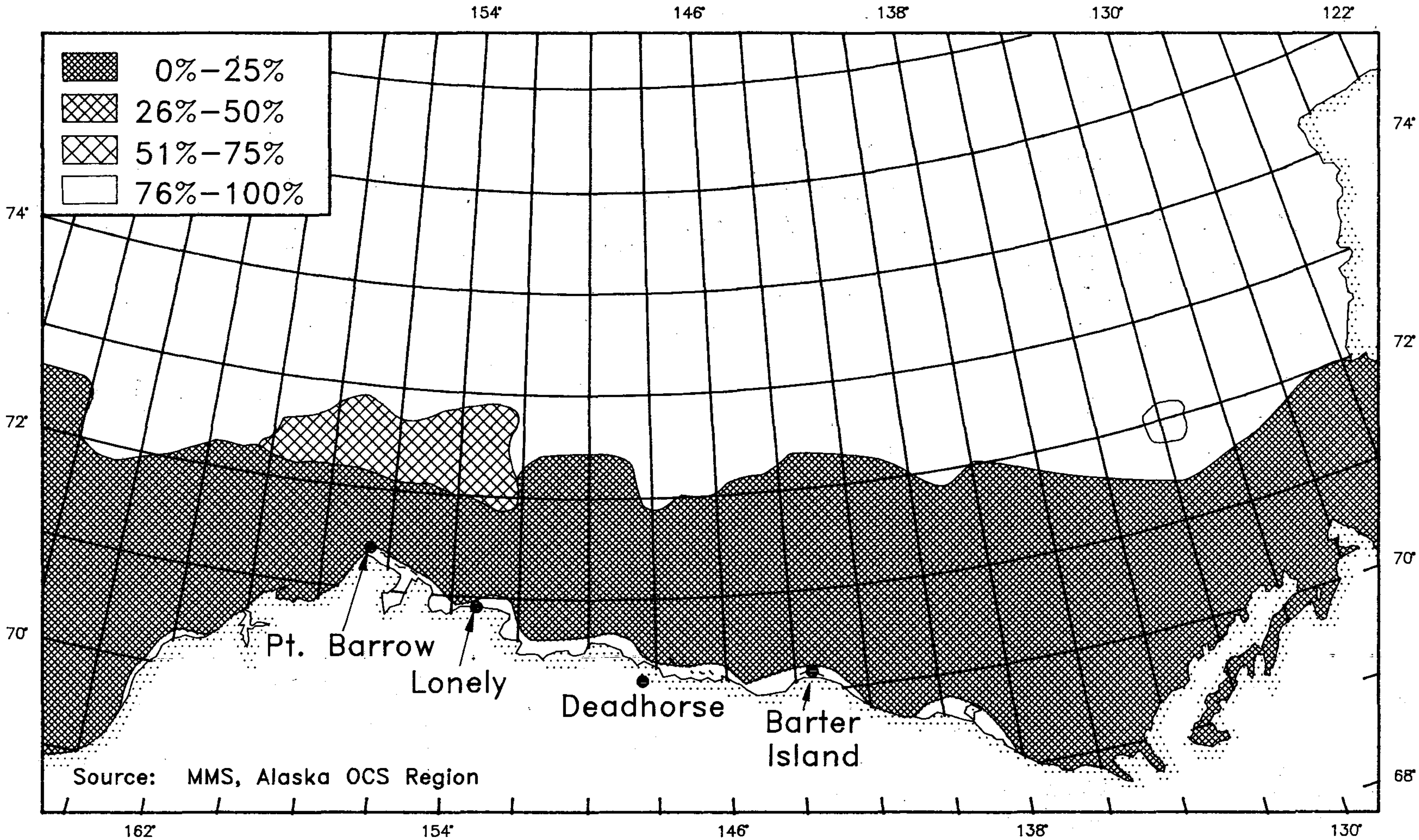


Figure 10. Map of Ice Concentrations in the Beaufort Sea, 20 October 1987

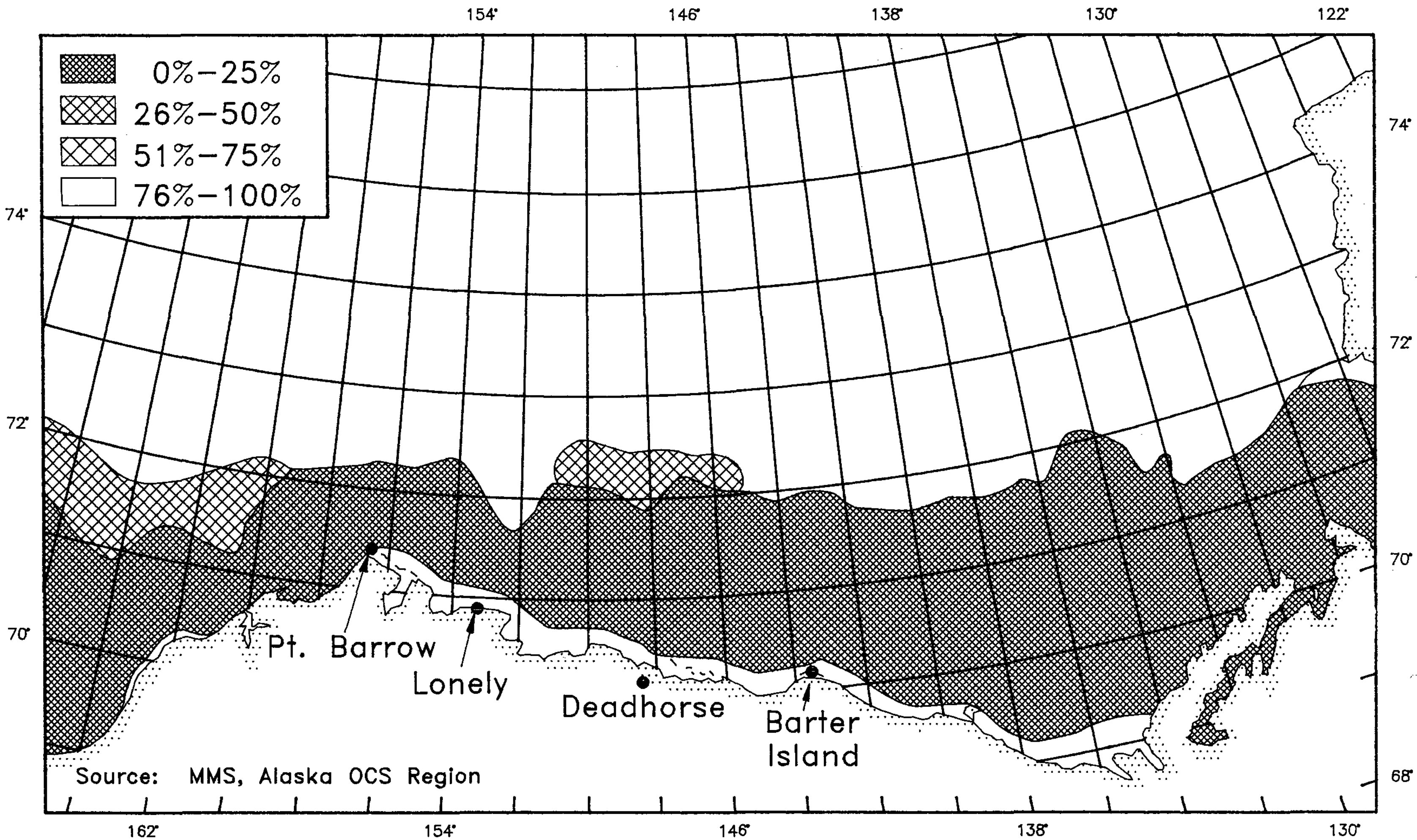


Figure 11. Map of Ice Concentrations in the Beaufort Sea, 27 October 1987

(Beaufort 1 to 2), to very poor, with visibility less than 1 km and high sea states (Beaufort 5 to 6). There was 99-percent new grease ice in coastal nearshore areas; and 60- to 95-percent new grease ice farther north to approximately 55 km offshore (Fig. 11). A narrow band of 10- to 25-percent broken floe ice was north of the grease ice, with open water beyond that. The Canadian Beaufort was completely open, except for coastal nearshore areas and north of the Mackenzie River, where there was 95-percent grease ice.

B. Survey Effort

Daily totals of kilometers and hours flown per survey flight are shown in Table 3. A total of 34,836 km of surveys were flown in 149.34 hours (Table 4) in the Beaufort Sea at an overall average speed of 233 km/h. Approximate survey speed for the Twin Otter was 230 km/h compared to 250 km/h for the Grumman Goose. A total of 14,870 km of random-transect lines were flown in 63.20 hours (Table 4) at an average speed of 235 km/h. These random transects constituted 42.7 percent of the total kilometers flown and 42.3 percent of the total flight hours. The number of flight hours over each survey block and bathymetric subregion is shown in subsequent analyses.

Day-to-day flight tracks for the Twin Otter aircraft are shown in Appendix B and the Grumman Goose aircraft in Appendix C. In general, survey-flight lines (Figs. 12 through 15) west of Deadhorse, Alaska, extended north to 72°N. latitude, while those east of Deadhorse extended north to 71°10'N. latitude.

During the first half of September (Fig. 12), almost all flight effort was concentrated east of Deadhorse in order to record the initial part of the westward migration of the bowhead whale. There were 19.24 hours of random transects flown from a total of 43.28 flight hours during this period (Table 4), constituting 30.4 percent and 29.0 percent, respectively, of the Fall-1987 study effort.

During the second half of September (Fig. 13), flight effort was increased west of Deadhorse as the bowhead migration progressed. There were 17.80 hours of random transects flown from 40.84 total flight hours during this period (Table 4), constituting 28.2 percent and 27.3 percent, respectively, of the overall fall effort.

During the first half of October (Fig. 15), survey coverage was equally balanced east and west of Deadhorse. There were 16.16 hours of random transects flown from 42.82 total flight hours during this period (Table 4), constituting 25.6 percent and 28.7 percent, respectively, of the overall fall effort.

During the last half of October (Fig. 15), flights were concentrated east of Deadhorse in order to provide additional survey coverage in the area of a Single Steel Drilling Caisson (SSDC) located east of Barter Island and to provide data needed by NMFS in order to determine the end of the fall bowhead migration. There were 10.00 hours of random transects flown from 22.40 total flight hours during this period (Table 4), constituting 15.8 percent and 15.0 percent, respectively, of the overall fall effort.

Table 3

Aerial-Survey Effort in the Beaufort Sea (east of 154°W. longitude), September-October 1987, by Survey Flight

Day	Aircraft	Flt. No.	Transect (km)	Connect (km)	Search (km)	Total (km)	Transect Time (h)	Total Survey Time (h)
2 Sep	TO[1/]	1	280	48	204	532	1.17	2.28
5 Sep	TO	2	272	62	519	853	1.10	3.67
6 Sep	TO	3	0	0	945	945	0.00	3.75
6 Sep	GG[2/]	5	650	100	272	1,022	2.52	3.93
8 Sep	TO	4	320	84	363	767	1.43	3.20
9 Sep	TO	5	442	92	463	997	1.77	4.30
10 Sep	TO	6	598	91	503	1,192	2.53	5.10
11 Sep	TO	7	535	80	394	1,009	2.65	4.92
12 Sep	TO	8	164	57	307	528	0.67	2.15
13 Sep	TO	9	0	0	165	165	0.00	0.68
14 Sep	TO	10	732	201	223	1,156	3.28	5.10
15 Sep	TO	11	513	143	288	944	2.12	4.20
16 Sep	TO	12	0	0	209	209	0.00	0.95
17 Sep	TO	13	567	164	375	1,106	2.52	4.80
18 Sep	TO	14	0	0	123	123	0.00	0.52
20 Sep	TO	15	91	51	850	992	1.38	4.22
21 Sep	TO	16	0	0	203	203	0.00	0.97
22 Sep	TO	17	438	114	393	945	2.08	4.63
22 Sep	GG	15	546	113	120	779	2.23	3.16
26 Sep	TO	18	361	124	87	572	1.23	2.62
27 Sep	TO	19	452	86	534	1,072	1.85	4.43
28 Sep	TO	20	279	101	225	605	1.25	2.67
28 Sep	TO	21	275	36	207	518	1.10	2.08
29 Sep	TO	22	498	195	293	986	2.23	4.57
30 Sep	TO	23	632	285	301	1,218	2.77	4.83
30 Sep	GG	21	29	0	65	94	0.15	0.40
1 Oct	TO	24	92	0	248	340	0.40	1.47
5 Oct	TO	25	428	130	674	1,232	1.73	5.12
5 Oct	TO	26	193	81	211	485	0.82	2.07
5 Oct	GG	24	534	116	158	808	2.17	3.40
6 Oct	TO	27	461	121	196	778	2.10	3.42
6 Oct	GG	25	0	0	68	68	0.00	0.42
7 Oct	TO	28	310	109	424	843	1.37	4.05
8 Oct	TO	29	366	107	215	688	1.57	3.28
9 Oct	TO	30	369	55	484	908	1.52	3.95
10 Oct	TO	31	489	99	482	1,070	2.20	4.77
11 Oct	TO	32	0	0	384	384	0.00	1.70
13 Oct	TO	33	0	0	673	673	0.00	3.00
14 Oct	TO	34	241	74	75	390	0.97	1.72
14 Oct	TO	35	227	82	227	536	0.92	2.18

Table 3

Aerial-Survey Effort in the Beaufort Sea (east of 154°W. longitude), September-October 1987, by Survey Flight (Continued)

Day	Aircraft	Flt. No.	Transect (km)	Connect (km)	Search (km)	Total (km)	Transect Time (h)	Total Survey Time (h)
15 Oct	TO	36	44	17	486	547	0.18	2.28
19 Oct	GG	33	50	0	19	69	0.22	0.29
21 Oct	GG	35	127	1	0	128	0.53	0.53
23 Oct	GG	36	89	22	29	140	0.37	0.59
25 Oct	GG	37	445	90	760	1,295	1.87	5.20
28 Oct	GG	38	389	109	580	1,078	1.52	4.30
29 Oct	GG	39	477	61	639	1,177	2.02	4.70
30 Oct	GG	40	526	156	196	878	2.12	3.50
31 Oct	GG	41	339	113	406	858	1.35	3.30

Source: MMS, Alaska OCS Region.

1/ TO = Twin Otter
2/ GG = Grumman Goose

Table 4

Semimonthly Summary of Survey Effort, Fall 1987

Semimonthly Period	No. Flights	No. Flight Days	Transect (km)	Connect (km)	Search (km)	Transect (h)	Survey Time (h)
1-15 Sep	12	11	4,505	958	4,646	19.24	43.28
16-30 Sep	14	11	4,169	1,268	3,986	17.80	40.84
1-15 Oct	15	11	3,754	991	4,936	16.16	42.82
16-31 Oct	8	8	2,442	552	2,629	10.00	22.40
TOTALS	49	41	14,870	3,769	16,197	63.20	149.34

Source: MMS, Alaska OCS Region.

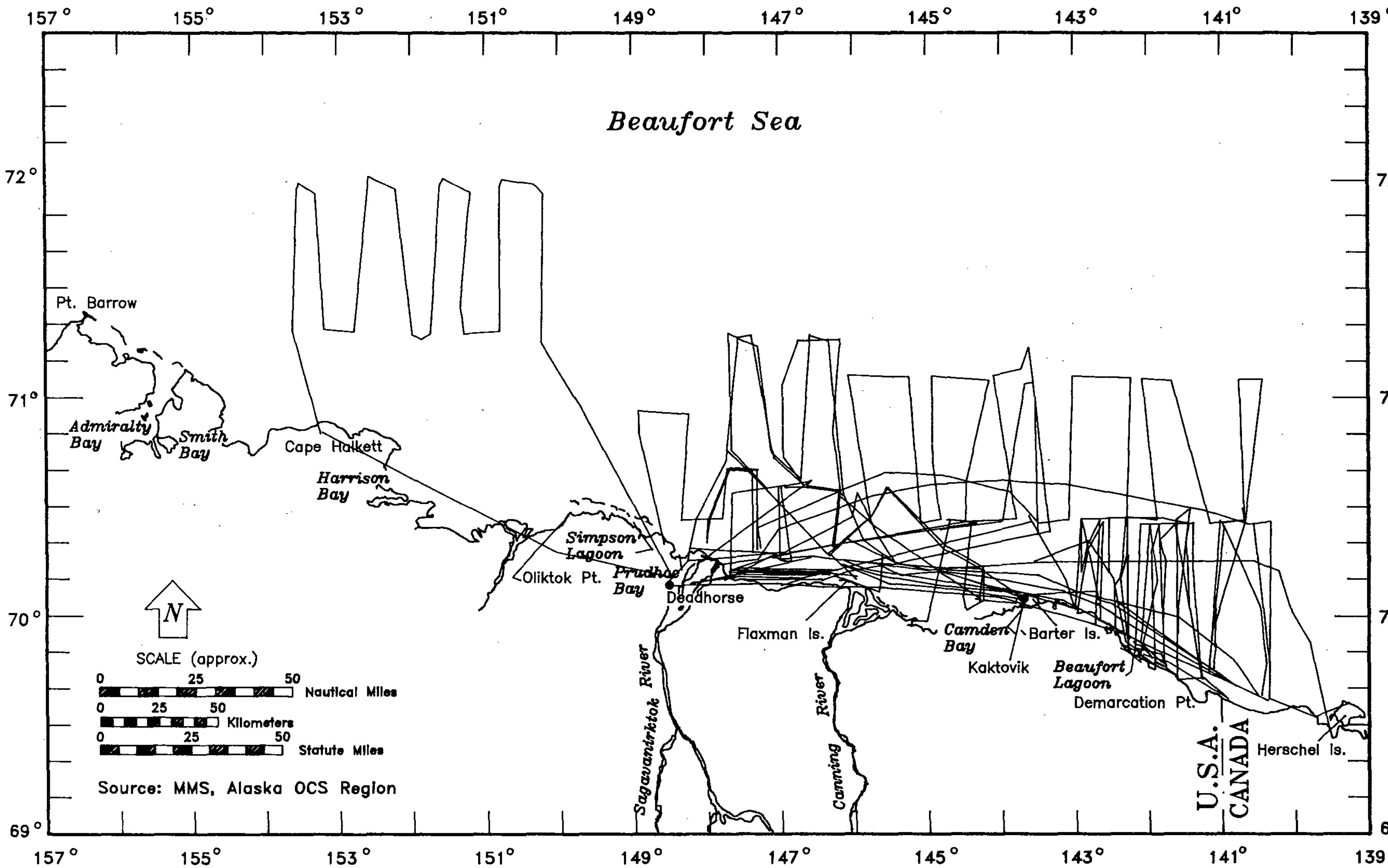


Figure 12. Combined Flight Tracks, 1–15 September 1987

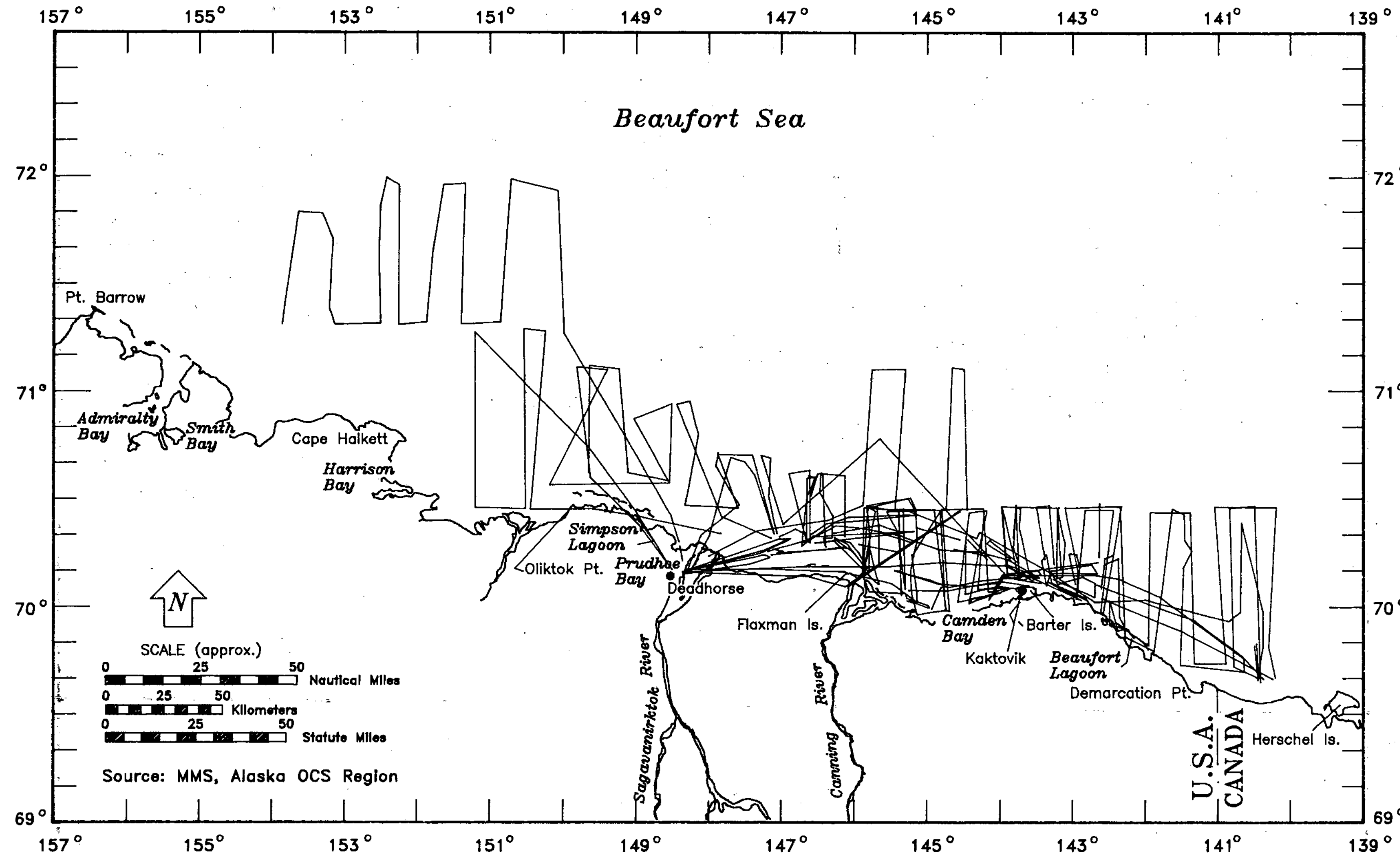


Figure 13. Combined Flight Tracks, 16–30 September 1987

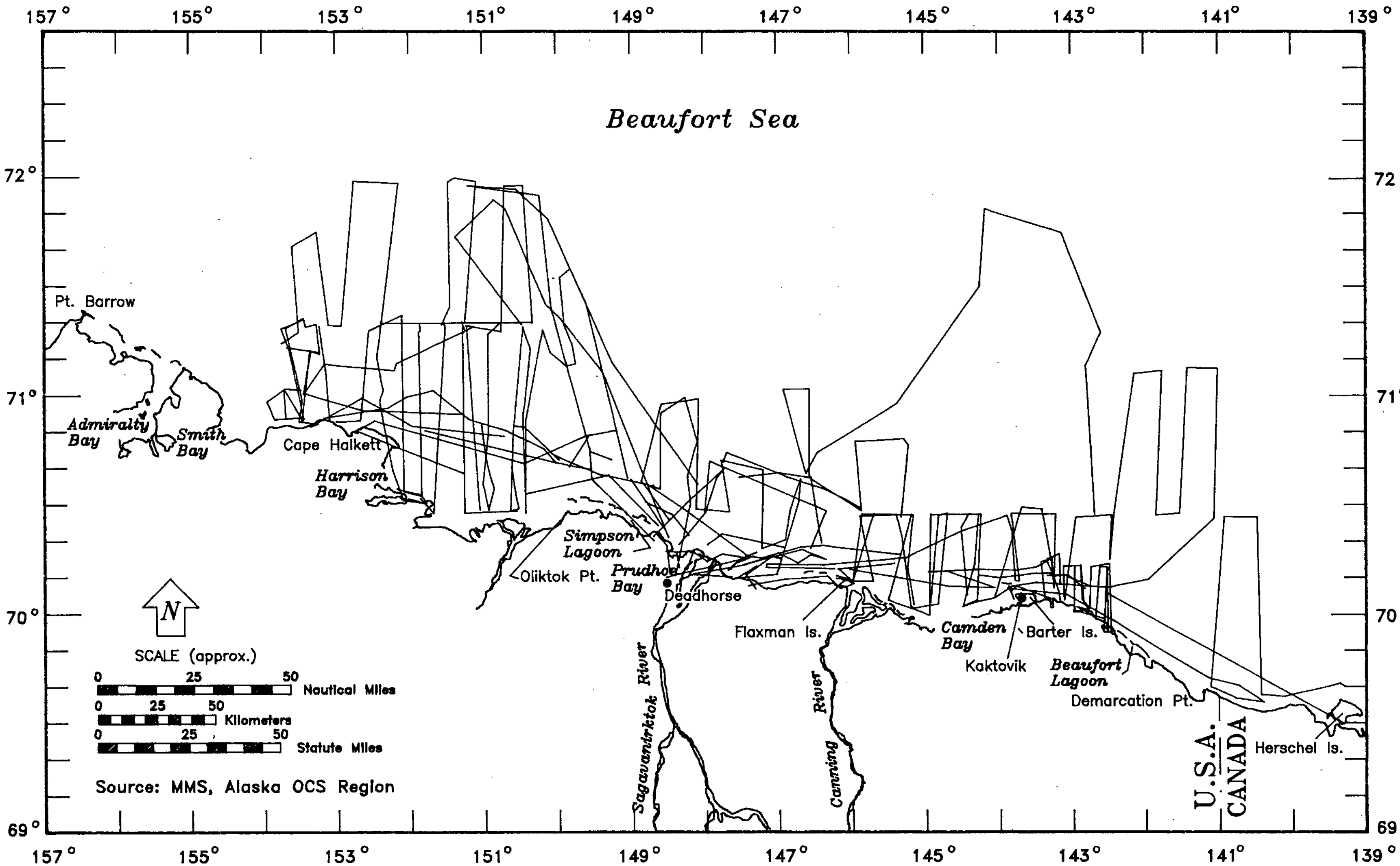


Figure 14. Combined Flight Tracks, 1–15 October 1987

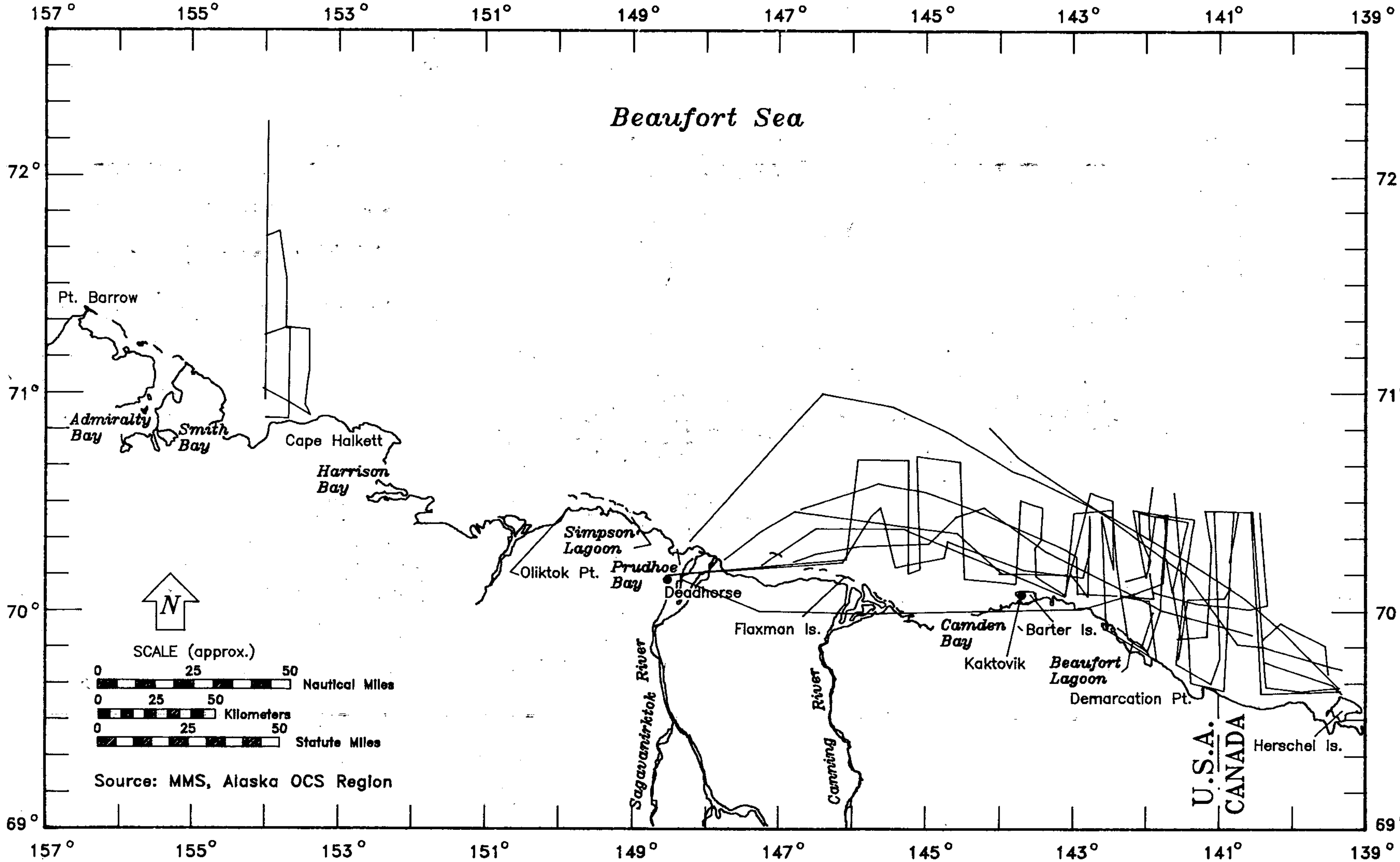


Figure 15. Combined Flight Tracks, 16–31 October 1987

C. Bowhead Whale (Balaena mysticetus) Observations

1. Distribution: There were 76 sightings of 110 bowhead whales made during Fall-1987 surveys in the study area (Table 5 and Figs. 16 through 19). Daily sightings are shown on individual maps in Appendices B and C.

During the first half of September (Fig. 16), 11 sightings of 13 bowhead whales were made. The first bowhead sighted (on 6 September) was east of the study area in Canadian waters, southeast of Herschel Island (Appendix B: Flight 3). The first bowhead sighted (on 9 September) in the Alaskan Beaufort was north of Barter Island (Appendix B: Flight 5). The westernmost sighting during this period was made northeast of Deadhorse, Alaska, on 15 September (Appendix B: Flight 11). Group sizes were small, with 81.8 percent of sightings representing single whales.

During the second half of September (Fig. 17), 42 sightings of 47 bowheads were made. The westernmost bowhead sighted during this timeframe--at 70°40.6'N. latitude, 148°08.4'W. longitude, on 30 September (Appendix B: Flight 23)--did not represent the vanguard of the migration, since four bowheads were sighted west of 154°W. longitude during this period (Ljungblad et al., 1988). Group sizes remained small, with 90.5 percent of the sightings representing single whales. The only calf sighted during this study was recorded on 29 September (Appendix B: Flight 22), resulting in an overall ratio of calves (number calves/total whales) of 0.01.

During the first half of October (Fig. 18), 20 sightings of 47 bowheads were made, with sightings somewhat equally distributed along the length of the coast. Whales were seen east of Barter Island as late as 13 October during this period (Appendix B: Flight 33). Group sizes increased substantially over September, with only 55 percent of the sightings representing single whales. The largest group (8 whales) was sighted on 7 October in close proximity to three other pods, for a total of 20 whales (Appendix B: Flight 28).

Three sightings of three bowheads were made in the eastern Alaskan Beaufort in late October (Fig. 19) during surveys flown in Blocks 4 through 7 to determine the status of the migration. The last bowhead seen in the Beaufort Sea occurred on 30 October at 70°17.5'N. latitude, 143°19.7'W. longitude (Appendix C: Flight 40). This was the latest sighting of a bowhead whale in the study area during the past 9 years of aerial surveys supported by MMS.

2. Relative Temporal and Spatial Abundance: A daily index of relative abundance, or whales per unit effort (WPUE = number of whales counted/h of survey effort), was calculated for bowhead whales (Table 6). When calculating relative abundance, all whale sightings were used regardless of the type of survey being conducted.

The day-to-day timing of the bowhead whale migration through the overall study area is shown in Table 6 and Figure 20. The initial sighting was made on 6 September. The daily sighting rate, or sightings per unit effort (SPUE), increased to 1.02 on 11 September and peaked at approximately three SPUE on 27 and 29 September. The SPUE decreased to 1.30 on 6 October. Between 14 and 31 October only three sightings were made, for an SPUE ranging from zero to 0.29. The last sighting of a bowhead in the study area was made on 30 October.

Table 5

Marine Mammal Species Sighted, Fall 1987
(number sightings/number animals)

Day	Aircraft	Flt. No.	Bowhead Whale	Beluga Whale	Bearded Seal	Ringed Seal	Unidentified Pinniped
Sightings per Survey Flight (2 Sep - 31 Oct)							
2 Sep	TO1/	1	0	0	0	0	0
5 Sep	TO	2	0	0	0	0	0
6 Sep	TO	3	1/1	0	0	1/15	0
6 Sep	GG2/	5	0	15/130	0	0	0
8 Sep	TO	4	0	0	0	0	0
9 Sep	TO	5	1/1	0	0	1/4	0
10 Sep	TO	6	1/1	0	0	5/40	2/7
11 Sep	TO	7	5/6	0	1/2	12/72	3/3
12 Sep	TO	8	0	0	0	0	0
13 Sep	TO	9	0	0	0	0	0
14 Sep	TO	10	1/1	3/17	0	0	0
15 Sep	TO	11	2/3	0	0	0	1/1
16 Sep	TO	12	1/3	0	1/1	0	0
17 Sep	TO	13	4/4	0	0	0	1/1
18 Sep	TO	14	0	0	0	0	0
20 Sep	TO	15	0	0	0	0	0
21 Sep	TO	16	0	0	0	0	0
22 Sep	TO	17	6/6	0	1/1	3/9	0
22 Sep	GG	15	0	1/1	2/2	0	1/1
26 Sep	TO	18	0	0	0	0	0
27 Sep	TO	19	13/14	0	0	0	0
28 Sep	TO	20	2/2	0	0	0	0
28 Sep	TO	21	0	0	0	0	0
29 Sep	TO	22	14/15	0	0	9/56	0
30 Sep	TO	23	2/3	0	1/1	2/32	0
30 Sep	GG	21	0	0	0	0	0
1 Oct	TO	24	0	0	0	0	0
5 Oct	TO	25	1/1	0	0	2/3	0
5 Oct	TO	26	1/1	0	3/3	5/23	0
5 Oct	GG	24	2/2	1/1	2/2	0	14/15
6 Oct	TO	27	3/8	0	0	2/8	0
6 Oct	GG	25	2/4	0	0	0	1/1
7 Oct	TO	28	4/20	0	1/1	4/10	1/1
8 Oct	TO	29	2/3	0	0	1/2	0
9 Oct	TO	30	0	1/1	0	2/9	0
10 Oct	TO	31	1/2	0	0	0	2/27
11 Oct	TO	32	0	0	0	0	0
13 Oct	TO	33	4/6	0	0	1/2	0
14 Oct	TO	34	0	0	0	0	0

Table 5

Marine Mammal Species Sighted, Fall 1987
(number sightings/number animals)
(Continued)

Day	Aircraft	Flt. No.	Bowhead Whale	Beluga Whale	Bearded Seal	Ringed Seal	Unidentified Pinniped
14 Oct	TO	35	0	0	0	0	0
15 Oct	TO	36	0	0	0	0	0
19 Oct	GG	33	0	0	0	0	0
21 Oct	GG	35	0	0	0	0	0
23 Oct	GG	36	0	0	0	0	0
25 Oct	GG	37	1/1	0	0	0	0
28 Oct	GG	38	1/1	0	0	0	1/1
29 Oct	GG	39	0	0	0	0	0
30 Oct	GG	40	1/1	0	0	0	0
31 Oct	GG	41	0	0	0	0	0
Total Semimonthly Sightings (1 Sep - 31 Oct)							
1-15 Sep			11/13	18/147	1/2	19/131	6/11
16-30 Sep			42/47	1/1	5/5	14/97	2/2
1-15 Oct			20/47	2/2	6/6	17/57	18/44
16-31 Oct			3/3	0	0	0	1/1
Total Seasonal Sightings							
Fall 1987			76/110	21/150	12/13	50/285	27/58

Source: MMS, Alaska OCS Region.

1/ TO = Twin Otter
2/ GG = Grumman Goose

Table 6

Number of Sightings and Total Bowhead Whales Counted per Hour of Survey Effort, by Flight Day (2 Sep - 31 Oct 1987)

Day	No. of Sightings	No. of Whales	Total Survey Time (h)	Sightings/ Hour (SPUE)	Whales/ Hour (WPUE)
2 Sep	0	0	2.28	0.00	0.00
5 Sep	0	0	3.67	0.00	0.00
6 Sep	1	1	7.68	0.13	0.13
8 Sep	0	0	3.20	0.00	0.00
9 Sep	1	1	4.30	0.23	0.23
10 Sep	1	1	5.10	0.20	0.20
11 Sep	5	6	4.92	1.02	1.22
12 Sep	0	0	2.15	0.00	0.00
13 Sep	0	0	0.68	0.00	0.00
14 Sep	1	1	5.10	0.20	0.20
15 Sep	2	3	4.20	0.48	0.71
16 Sep	1	3	0.95	1.05	3.16
17 Sep	4	4	4.80	0.83	0.83
18 Sep	0	0	0.52	0.00	0.00
20 Sep	0	0	4.22	0.00	0.00
21 Sep	0	0	0.97	0.00	0.00
22 Sep	6	6	7.79	0.77	0.77
26 Sep	0	0	2.62	0.00	0.00
27 Sep	13	14	4.43	2.93	3.16
28 Sep	2	2	4.75	0.42	0.42
29 Sep	14	15	4.57	3.06	3.28
30 Sep	2	3	5.23	0.38	0.57
1 Oct	0	0	1.47	0.00	0.00
5 Oct	4	4	10.59	0.38	0.38
6 Oct	5	12	3.84	1.30	3.13
7 Oct	4	20	4.05	0.99	4.94
8 Oct	2	3	3.28	0.61	0.91
9 Oct	0	0	3.95	0.00	0.00
10 Oct	1	2	4.77	0.21	0.42
11 Oct	0	0	1.70	0.00	0.00
13 Oct	4	6	3.00	1.33	2.00
14 Oct	0	0	3.90	0.00	0.00
15 Oct	0	0	2.28	0.00	0.00
19 Oct	0	0	0.29	0.00	0.00
21 Oct	0	0	0.53	0.00	0.00
23 Oct	0	0	0.59	0.00	0.00
25 Oct	1	1	5.20	0.19	0.19
28 Oct	1	1	4.30	0.23	0.23
29 Oct	0	0	4.70	0.00	0.00
30 Oct	1	1	3.50	0.29	0.29
31 Oct	0	0	3.30	0.00	0.00

Source: MMS, Alaska OCS Region.

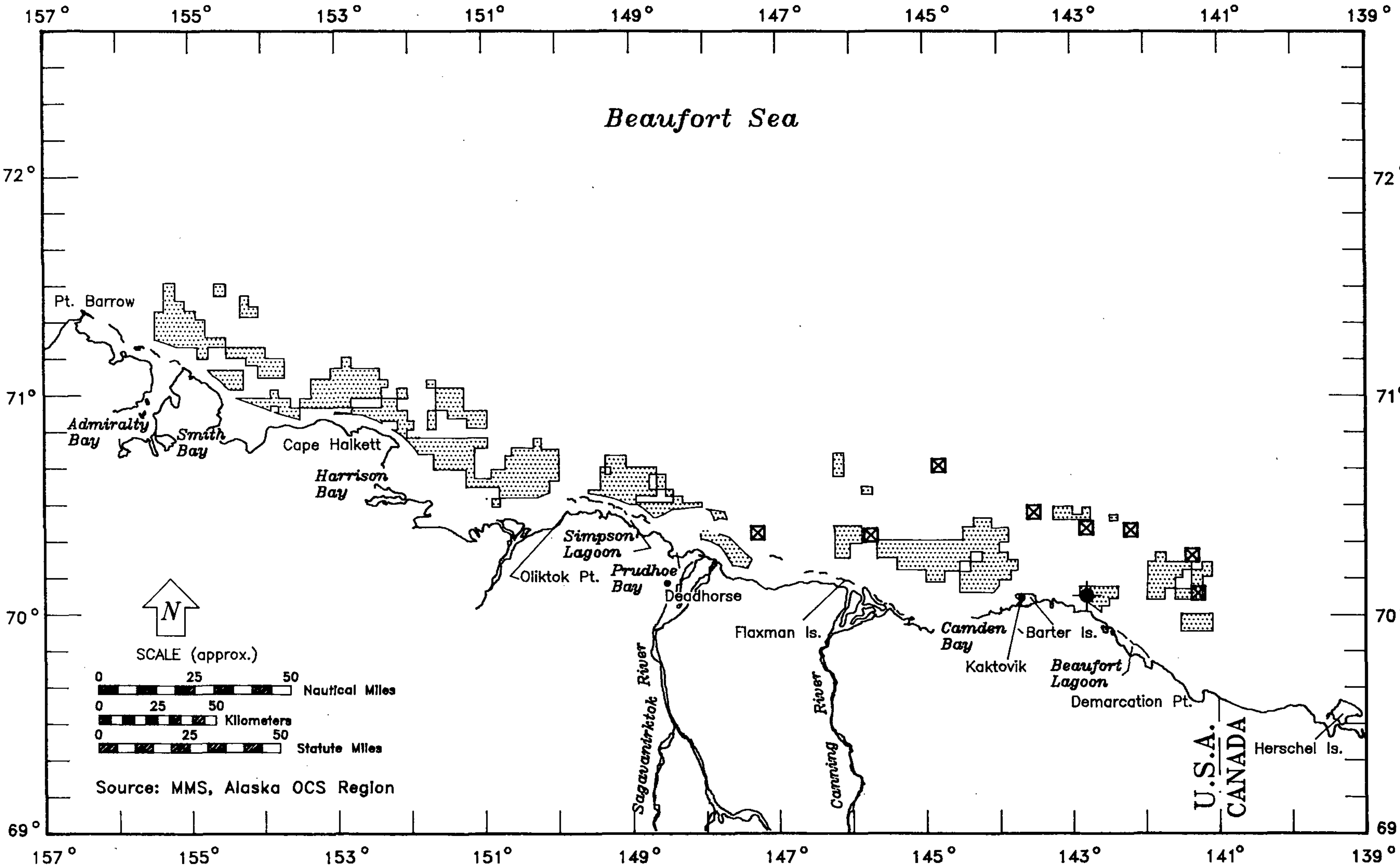


Figure 16. Map of Bowhead Whale Sightings (⊠), 1–15 September 1987, Showing 1987 Lease Tracts (shaded areas) and Position of SSDC (-●-)

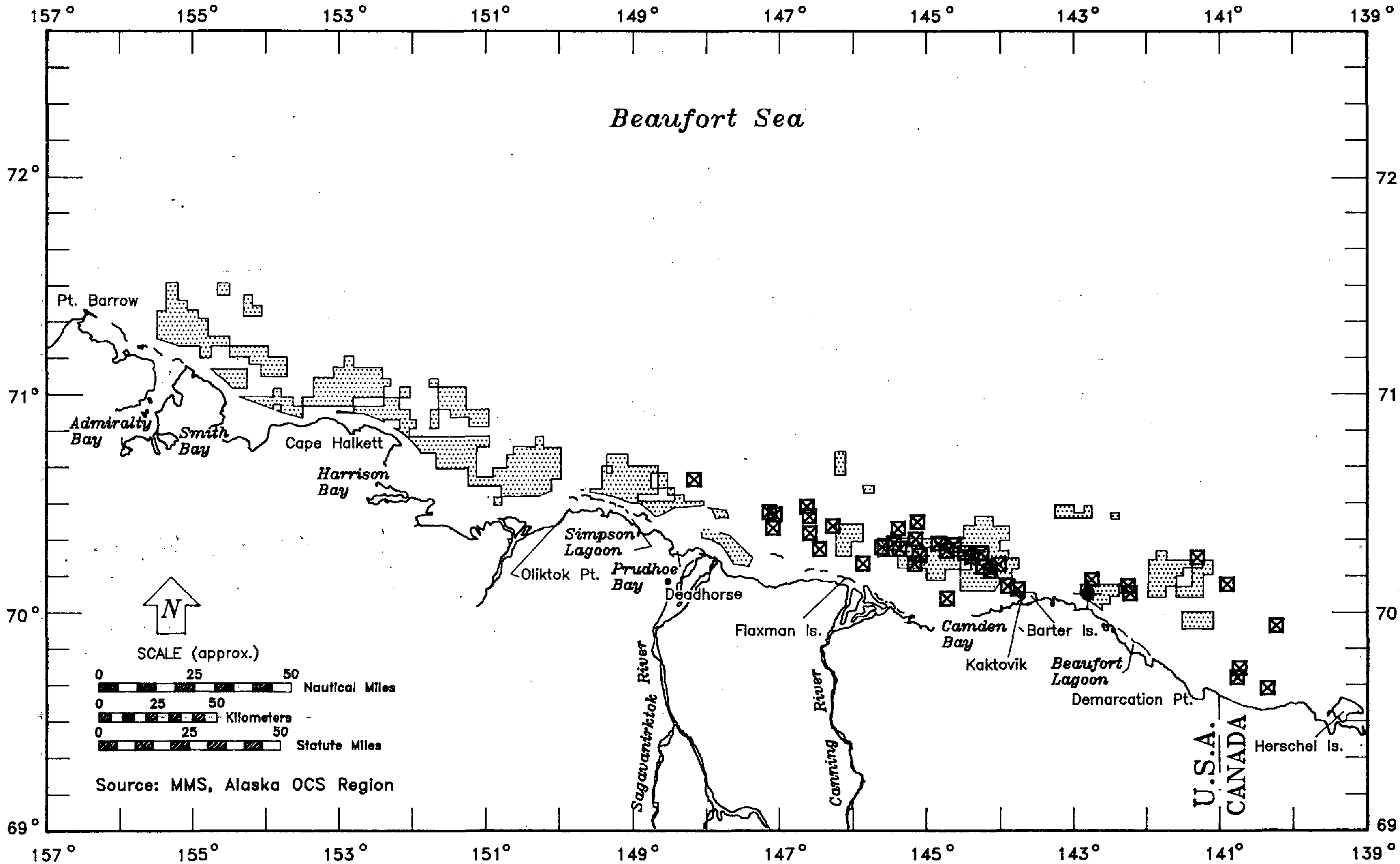


Figure 17. Map of Bowhead Whale Sightings (⊠), 16–30 September 1987, Showing 1987 Lease Tracts (shaded areas) and Position of SSDC (⯁)

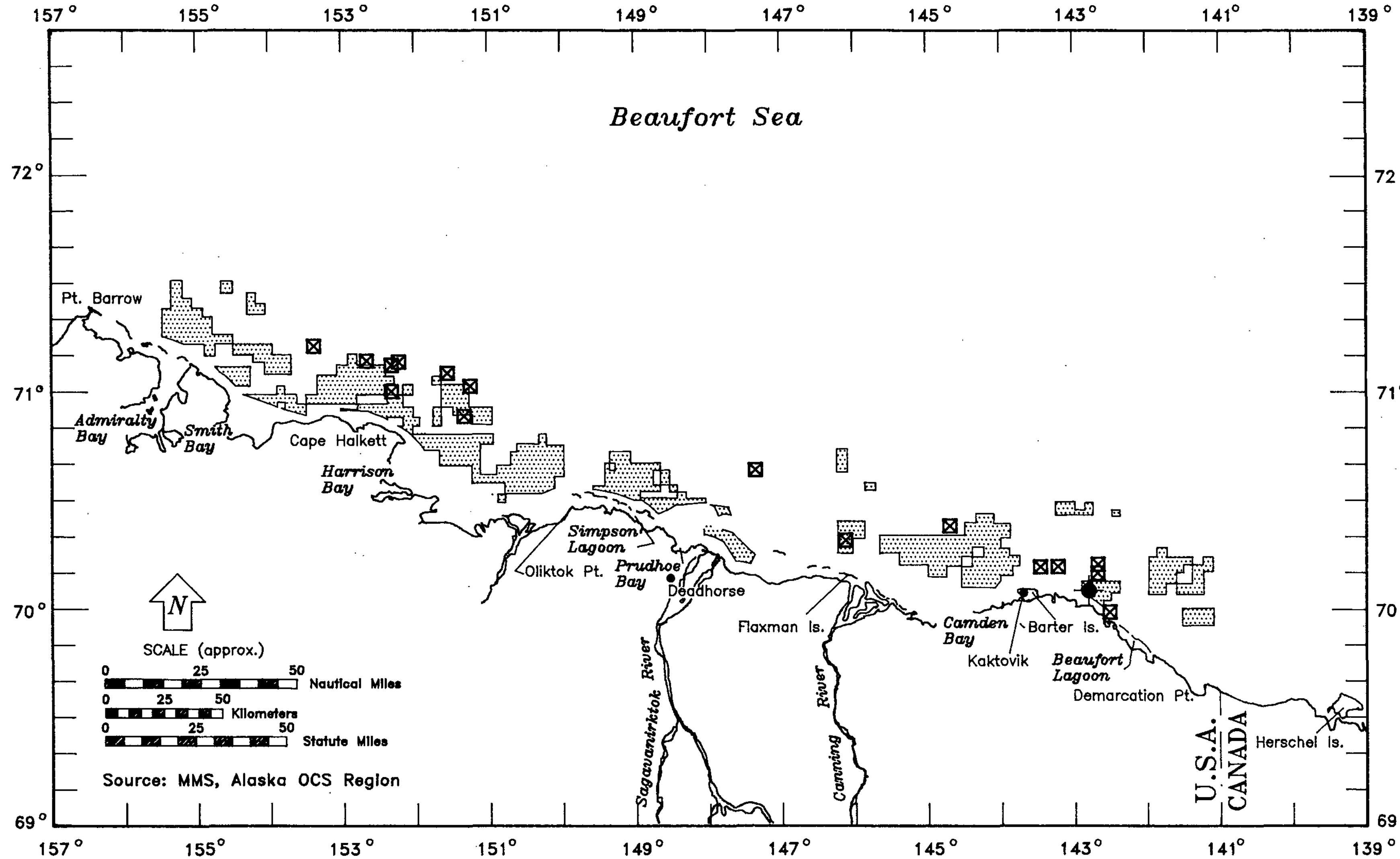


Figure 18. Map of Bowhead Whale Sightings (⊠), 1–15 October 1987, Showing 1987 Lease Tracts (shaded areas) and Position of SSDC (●).

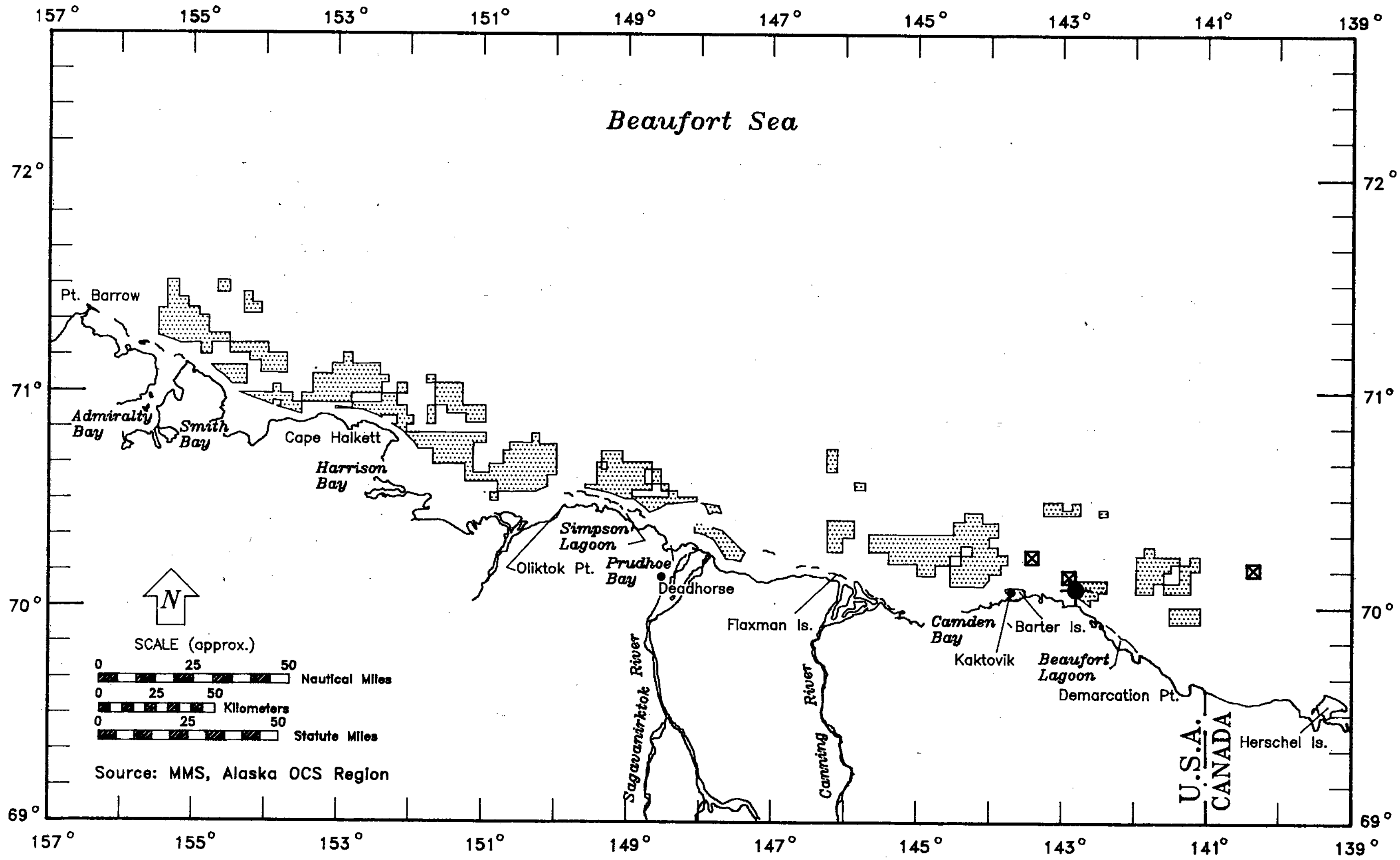
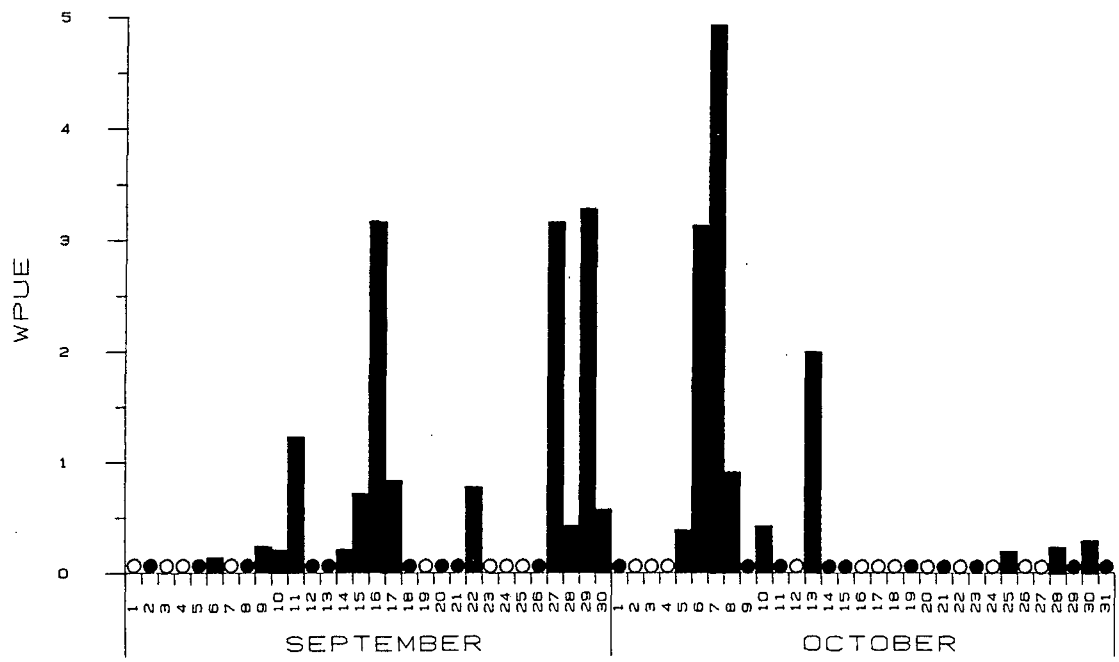
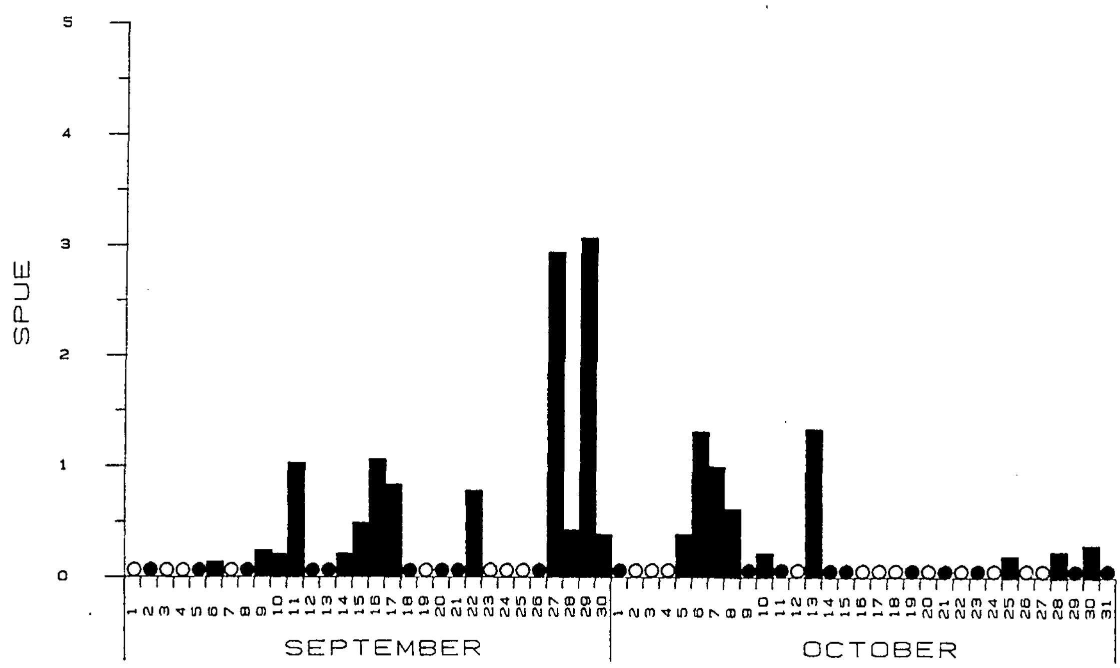


Figure 19. Map of Bowhead Whale Sightings (⊠), 16–31 October 1987, Showing 1987 Lease Tracts (shaded areas) and Position of SSDC (-◆-)





Source: MMS, Alaska OCS Region

Figure 20. Total Bowhead Whales Counted per Hour (WPUE) and Sightings per Hour (SPUE), by Calendar Day (Fall 1987)

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

The major differences between the relative abundance and the sighting rate for all areas surveyed occur on 16 September (Fig. 20), when a single sighting of three bowheads within only 0.95 hours of survey effort resulted in what probably is an artificially high relative abundance of 3.16 WPUE (Table 6). The higher WPUE's (relative to SPUE) on 6 and 7 October are due to the large pod sizes recorded on those days. The midpoint (median) of the bowhead migration through the study area (when 50% of all sighted whales had been recorded) occurred on 29 September (Table 6). The WPUE shows a peak relative abundance (mode) of 4.94 on 7 October (Table 6 and Fig. 20).

The relative abundance of bowhead whales in each survey block in Canadian waters east of 140°W. longitude, and in Alaskan waters outside of study-area blocks, was calculated for Table 7. A comparison of the total effort-hours in each survey block with the number of bowheads sighted also is shown in Figure 21.

During the first half of September, there were four survey blocks in which 4 or more hours of survey effort were made (Table 7). Of these (Blocks 1, 4, 5, and 6), only Block 5--which is inshore at the Canadian/Alaskan border--had a relative abundance (0.51 WPUE) greater than 0.5. No whales were observed during a total of 9.13 hours of survey effort in any of the remaining blocks (Blocks 2, 3, 7, 8, 9, 10, and 11). One whale observed during only 1.51 hours in Canada east of 140°W. longitude resulted in an artificially high WPUE of 0.66.

During the second half of September, there were three blocks in which 4 or more hours of survey effort were made (Table 7). All three of these eastern coastal blocks (Blocks 1, 4, and 5) had relative abundances (1.08, 1.86, 1.04 WPUE, respectively) greater than 0.50. No whales were observed during a total of 6.65 hours of survey effort in any of the remaining blocks (Blocks 2, 3, 6, 7, 8, 9, 10, and 11).

During the first half of October, there were five blocks in which 4 or more hours of survey effort were made (Table 7). Of these (Blocks 1, 3, 4, 5, and 11), Blocks 3, 4, and 5 along the coast each had a relative abundance greater than 0.50 WPUE (3.14, 0.81, and 0.66 WPUE, respectively). The 3.14 WPUE recorded for Block 3, at the southwestern corner of the study area, was by far the highest relative abundance for any block on a semimonthly basis. No whales were observed during a total of 5.22 hours of survey effort in any of the remaining blocks (Blocks 2, 6, 7, 8, 9, and 10).

During the last half of October, 4 or more hours of survey effort were made only in Block 5 (Table 7). This block, at the southeastern corner of the study area, had a relative abundance of only 0.18 WPUE. Only one whale was observed during a total of 8.59 hours of survey effort in any of the remaining blocks.

3. Habitat Relationships: Almost all bowheads (95%) were sighted in shallow water (0-50 m deep). The few remaining (5%) were sighted in water ranging from 51 m to a maximum depth of 79 m (Table 8). A fuller description of depth associated with the bowhead migration, based on more accurate depth values, appears in the discussion on median-water-depth analysis in Section IV.B. The number of bowheads observed on transect, with associated survey times, is shown by bathymetric subregion in Appendix A.

Table 7

Semimonthly Relative Abundance (WPUE) of Bowhead Whales (BH[1/]) (Fall 1987), by Survey Block

Block	1-15 Sep			16-30 Sep			1-15 Oct			16-31 Oct			TOTAL		
	Hours	BH	WPUE	Hours	BH	WPUE	Hours	BH	WPUE	Hours	BH	WPUE	Hours	BH	WPUE
1	7.79	2	0.26	11.06	12	1.08	9.21	2	0.23	1.28	0	0.00	29.34	16	0.55
2	2.59	0	0.00	0.12	0	0.00	1.16	0	0.00	0.24	0	0.00	4.11	0	0.00
3	0.84	0	0.00	1.72	0	0.00	11.45	36	3.14	0.79	0	0.00	14.80	36	2.43
4	6.26	1	0.16	13.42	25	1.86	7.45	6	0.81	3.85	1	0.26	30.98	33	1.07
5	13.85	7	0.51	9.65	10	1.04	4.58	3	0.66	10.91	2	0.18	38.99	22	0.56
6	4.54	2	0.44	1.82	0	0.00	0.91	0	0.00	1.57	0	0.00	8.84	2	0.28
7	2.89	0	0.00	0.06	0	0.00	1.72	0	0.00	0.46	0	0.00	5.13	0	0.00
8	0.00	0	0.00	0.00	0	0.00	0.35	0	0.00	0.00	0	0.00	0.35	0	0.00
9	0.24	0	0.00	0.00	0	0.00	0.56	0	0.00	0.00	0	0.00	0.80	0	0.00
10	0.00	0	0.00	0.00	0	0.00	0.52	0	0.00	0.00	0	0.00	0.52	0	0.00
11	2.57	0	0.00	2.93	0	0.00	4.44	0	0.00	0.40	0	0.00	10.34	0	0.00
Canada[2/]	1.51	1	0.66	0.00	0	0.00	0.47	0	0.00	2.68	0	0.00	4.66	1	0.21
Unblocked[3/]	0.20	0	0.00	0.06	0	0.00	0.00	0	0.00	0.22	0	0.00	0.48	0	0.00
TOTAL	43.28	13	0.30	40.84	47	1.15	42.82	47	1.10	22.40	3	0.13	149.34	110	0.74

Source: MMS, Alaska OCS Region.

1/ BH = Bowhead.
2/ Canadian waters east of 140°W. longitude.
3/ Values in this column are based on survey effort in Alaskan arctic waters outside established survey blocks.

Table 8

Semimonthly Summary of Bowhead Whales Counted (Fall 1987), by Water Depth at Sighting Location

Water Depth	1-15 Sep No. (%)	16-30 Sep No. (%)	1-15 Oct No. (%)	16-31 Oct No. (%)	Total No. (%)
Shallow (0-50 m)	10 (77)	45 (96)	47 (100)	2 (67)	104 (95)
Transitional (51-200 m)	3 (23)	2 (4)	0	1 (33)	6 (5)
Deepest Sighting	79 m	59 m	48 m	63 m	79 m
TOTAL	13 (100)	47 (100)	47 (100)	3 (100)	110 (100)

Source: MMS, Alaska OCS Region.

Table 9

Semimonthly Summary of Bowhead Whales Counted (Fall 1987), by Percent Ice Cover Present at Sighting Location

%Ice Cover	1-15 Sep No. (%)	16-30 Sep No. (%)	1-15 Oct No. (%)	16-31 Oct No. (%)	Total No. (%)
0	11 (85)	46 (98)	47 (100)	1 (33)	105 (95)
1-5	1 (7.5)	1 (2)	0	1 (33)	3 (3)
6-10	1 (7.5)	0	0	0	1 (1)
61-70	0	0	0	1 (33)	1 (1)
TOTAL	13 (100)	47 (100)	47 (100)	3 (100)	110 (100)

Source: MMS, Alaska OCS Region.

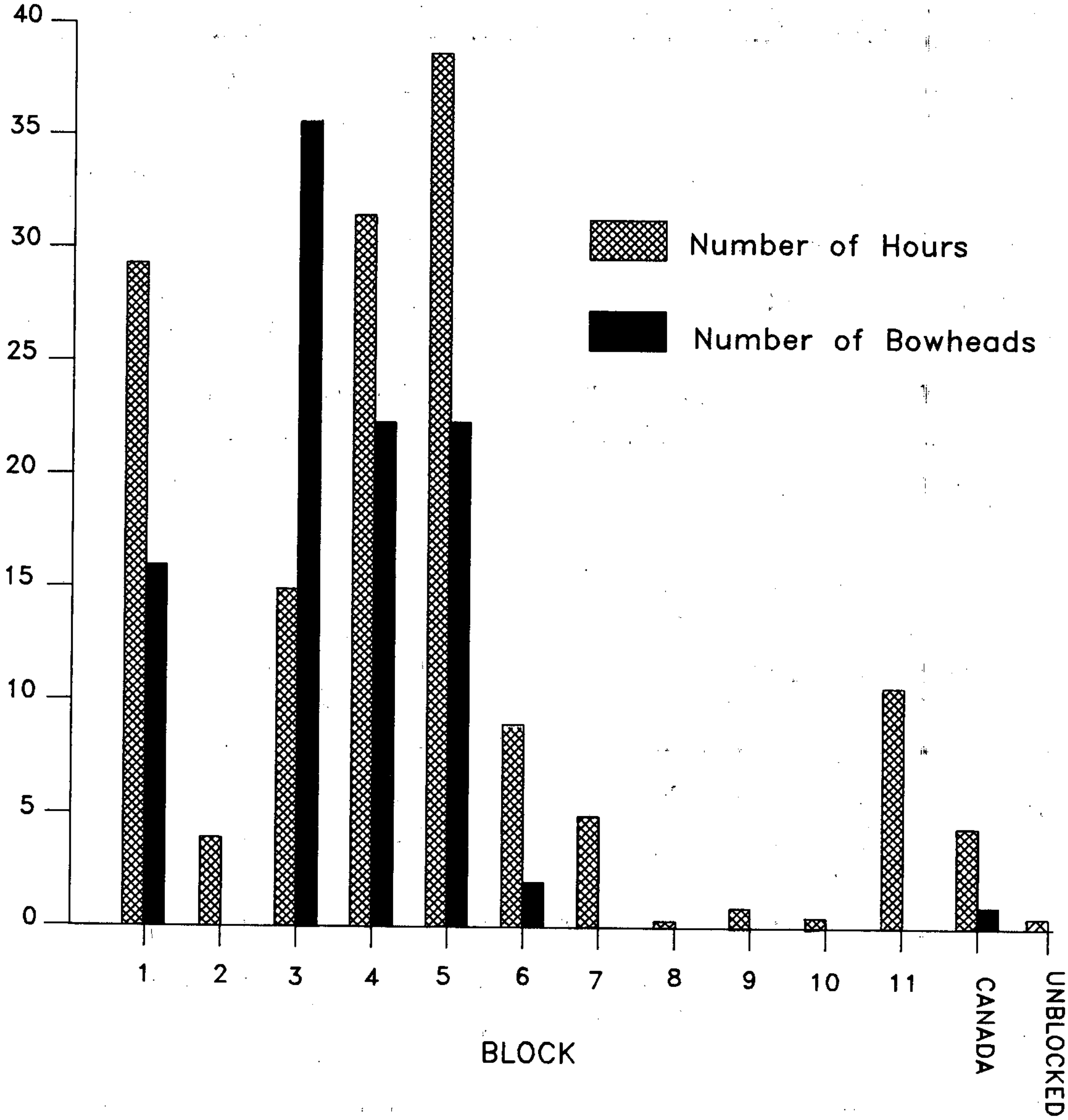


Figure 21. Number of Survey Hours and Number of Bowhead Whales Counted September–October 1987, by Survey Block

Almost all bowheads were sighted in open water (95%), with only 5 percent of whales sighted in any association with sea ice (Table 9). This was a year with extremely light ice conditions in the Beaufort Sea during September and October. Ice concentrations during this time period are shown in Figures 4 through 11.

4. Behavior, Swim Direction, and Speed: Overall, 78 (71%) of the bowheads observed during Fall 1987 were swimming, i.e., moving forward in an apparently deliberate manner (Table 10 and Fig. 22). Swim speeds were primarily at a medium rate (2-4 km/h) (Table 11). Swim direction over the fall season was predominantly split between west-southwest and west-northwest (Fig. 23), consistent with an overall westerly migration.

During the first half of September, nearly all (92%) bowheads were listed as swimming (Table 10). Most swimming whales were headed in a west-northwesterly direction (Fig. 23), corresponding with a direct migratory route along the Beaufort Sea coastline, at a medium (46%) or fast (39%) rate of speed. On 11 September, one whale was observed--apparently playing with a large floating log.

During the second half of September, most bowheads (77%) were seen swimming either in a west-southwesterly or west-northwesterly direction, generally at medium speed (51%). Some whales (17%) were resting when sighted during this period.

During the first half of October, only slightly more than half (57%) of the bowheads were seen swimming. These whales were headed primarily west-southwest and secondarily west-northwest. Of just those whales for which swimming speeds were noted, most (57%) were moving at medium speed. During this period, a large percentage (41%) of whales observed were feeding when sighted. All Fall-1987 feeding whales were observed on 7 October (Appendix B: Flight 28), in three neighboring pods at approximately 70°57'N. latitude, 151°17'W. longitude--northeast of Cape Halkett, Alaska.

During the last half of October, only three bowheads were sighted, all swimming west-southwest (240°) at medium (67%) or slow (33%) speeds.

D. Other Marine Mammal Observations

1. Beluga Whale (*Delphinapterus leucas*): Nineteen sightings of 148 beluga whales were made during September in the area surveyed (Table 5). During September, the overall relative abundance of belugas was 1.76 WPUE. During October, only two belugas were sighted. Fall sightings were clustered primarily between 70°40'N. and 71°10'N. latitudes, north of Harrison Bay (Fig. 24). The sightings nearest to shore tended to correspond with the 200-m isobath. Pod sizes generally ranged from 1 to 25 whales.

Of the belugas seen in September and October 1987, 15 sightings of 130 whales were made on a single day, 6 September, in Block 11 or the unblocked area directly north of Block 11. Belugas seen on 6 September (Appendix C: Flight 5) largely accounted for relative abundances in September of 10.13 WPUE in Block 11 and 26.67 WPUE north of Block 11. Of the 130 belugas seen on that day, 20 (15.4%) were identified as calves on the basis of relative size. Ice cover associated with sightings on 6 September ranged from 10 to 50 percent,

Table 10

Semimonthly Summary of Bowhead Whales Counted (Fall 1987), by Behavioral Category

Behavior	1-15 Sep No. (%)	16-30 Sep No. (%)	1-15 Oct No. (%)	16-31 Oct No. (%)	Total No. (%)
Locomotive					
Swim	12 (92)	36 (77)	27 (57)	3 (100)	78 (71)
Dive	0	2 (4)	1 (2)	0	3 (3)
Physiological					
Rest	0	8 (17)	0	0	8 (7)
Feed	0	0	9 (41)	0	19 (17)
Mill	1 (8)	0	0	0	1 (1)
Unknown	0	1 (2)	0	0	1 (1)
TOTAL	13 (100)	47 (100)	47 (100)	3 (100)	110 (100)

Source: MMS, Alaska OCS Region.

Table 11

Semimonthly Summary of Bowhead Whales Counted (Fall 1987), by Swimming Speed

Swim Speed	1-15 Sep No. (%)	16-30 Sep No. (%)	1-15 Oct No. (%)	16-31 Oct No. (%)	Total No. (%)
Still (0 km/h)	0	9 (19)	0	0	9 (8)
Slow (<2 km/h)	2 (15)	2 (4)	4 (8)	1 (33)	9 (8)
Medium (2-4 km/h)	6 (46)	24 (51)	17 (36)	2 (67)	49 (45)
Fast (>4 km/h)	5 (39)	9 (19)	6 (13)	0	20 (18)
Unknown	0	3 (6)	20 (43)	0	23 (21)
TOTAL	13 (100)	47 (100)	47 (100)	3 (100)	110 (100)

Source: MMS, Alaska OCS Region.

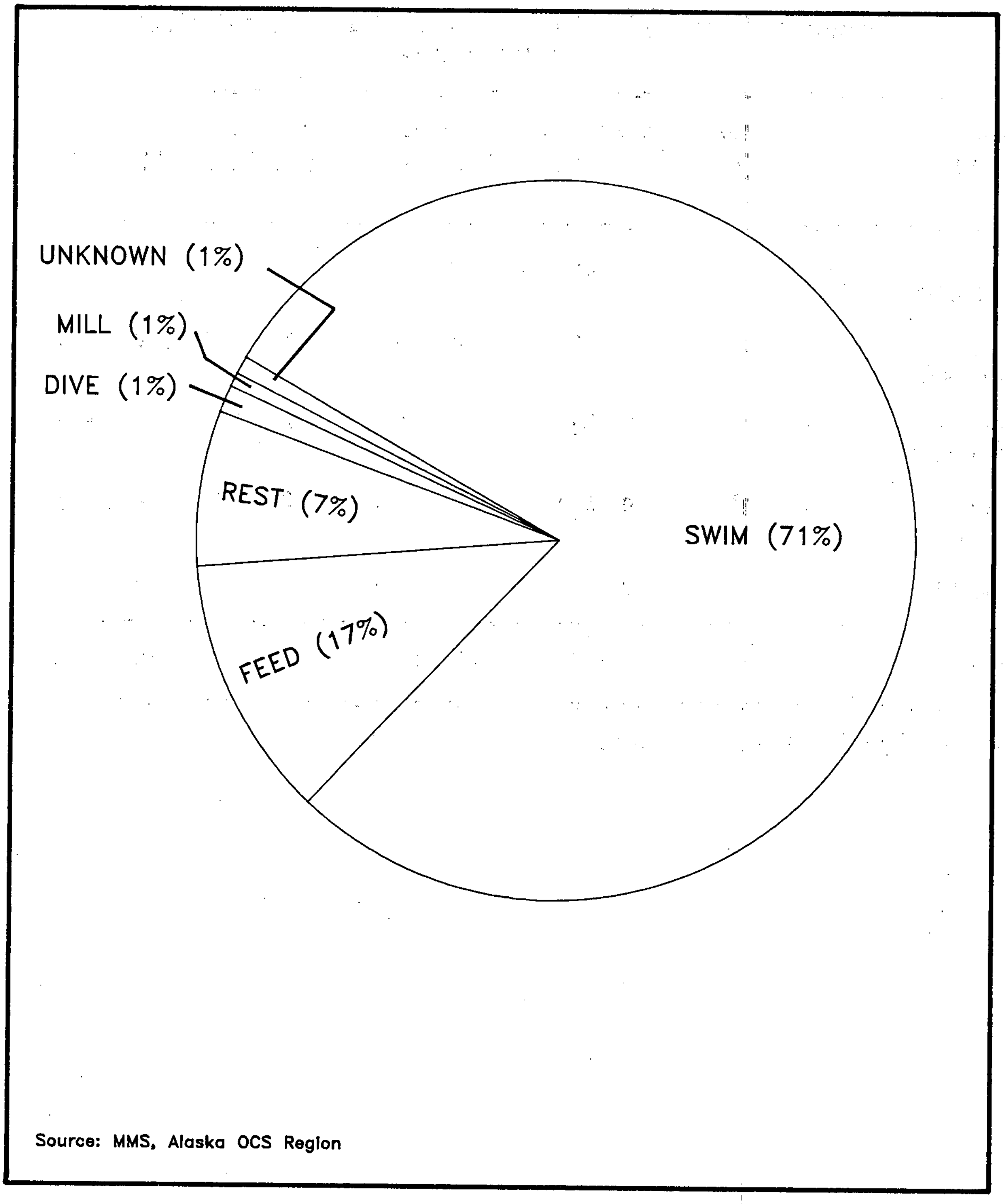
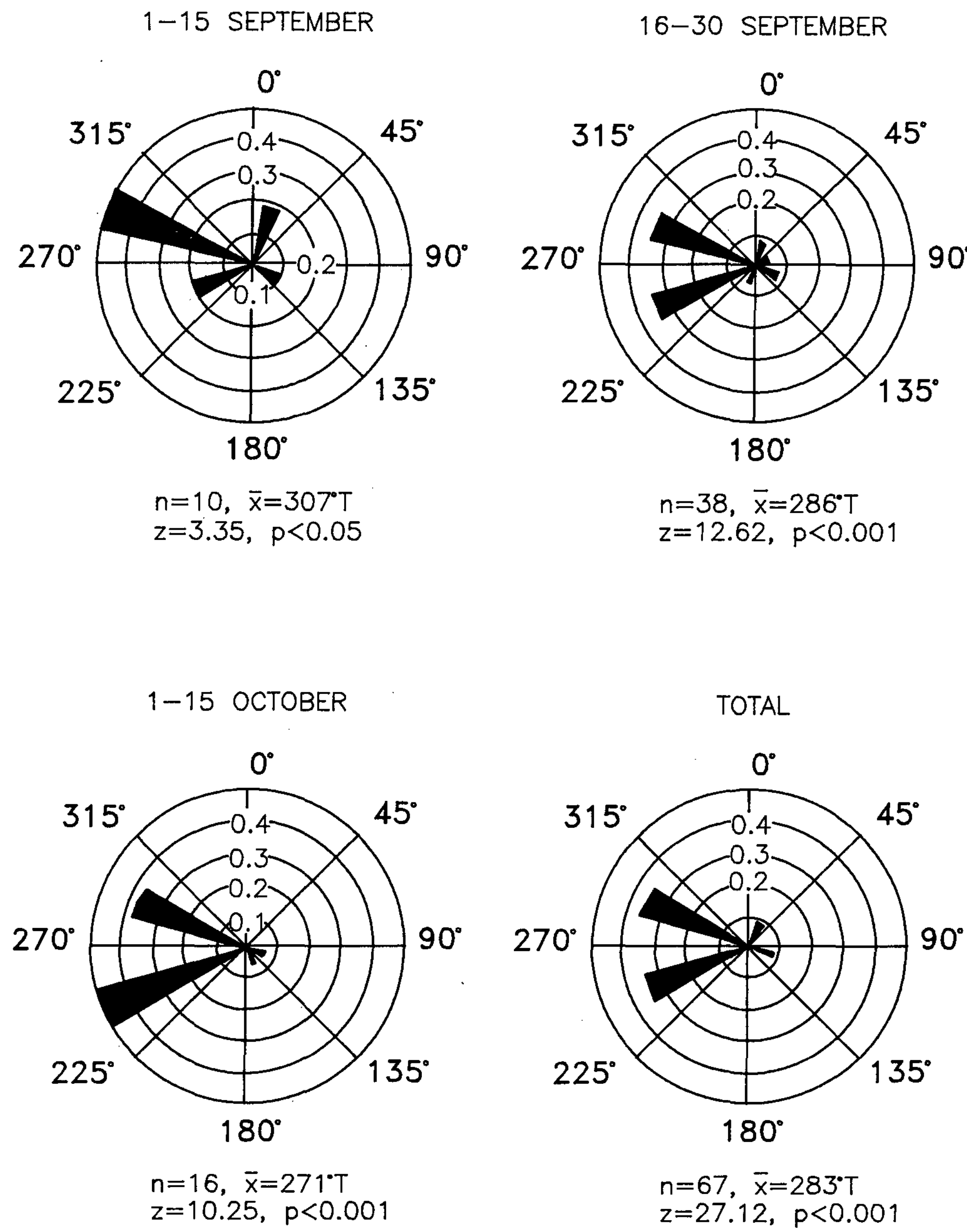


Figure 22. Summary of Bowhead Whale Behaviors Observed (Fall 1987)



Source: MMS, Alaska OCS Region

Figure 23. Semimonthly Summary of Swim Directions for Bowhead Whales (Fall 1987)

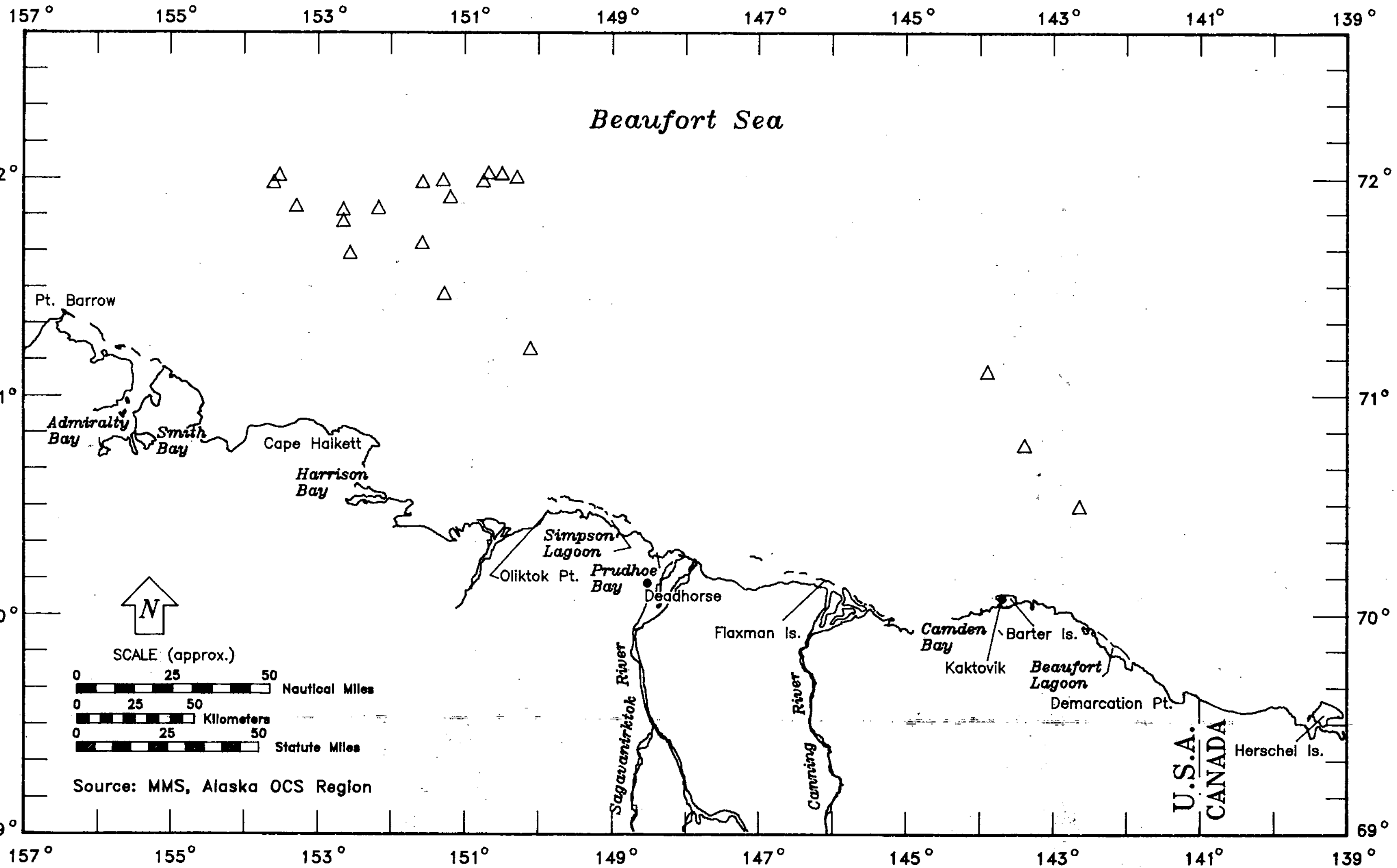


Figure 24. Map of Beluga Whale Sightings (△), September–October 1987

mostly broken floe. The 15 pods sighted were swimming at a slow rate of speed and were not clustered about any particular heading.

In addition to bowhead whales, belugas were the only other cetacean observed in the study area from September to October 1987.

2. Ringed Seal (*Phoca hispida*): Fifty incidental sightings of 285 ringed seals were made during September and the first half of October (Table 5). Sightings during this period (Fig. 25) were in open water and largely clustered in Blocks 4 and 5, corresponding with higher survey effort (30.98 h and 38.99 h, respectively) in those blocks (Table 7). Relatively few pods of ringed seals were sighted, however, in coastal Blocks 1 and 3--even though effort in these blocks was fairly high (29.34 h and 14.80 h, respectively). No ringed seals were sighted during the last half of October.

3. Bearded Seal (*Erignathus barbatus*): Twelve incidental sightings of 13 bearded seals were made during September and the first half of October (Table 5). All but one of these sightings were of individual seals. Sightings during this period (Fig. 26) tended to fall between the 50-m and 200-m isobaths in open water. No bearded seals were sighted during the last half of October.

4. Unidentified Pinnipeds: Twenty-seven incidental sightings of unidentified pinnipeds were made during September and October. Distribution of these sightings (Fig. 27) was primarily in Blocks 3 and 11, in open water.

5. Polar Bear (*Ursus maritimus*): Although polar bears have been observed during previous surveys, none were seen from aircraft this year--perhaps due to the extreme ice-free conditions in the study area.

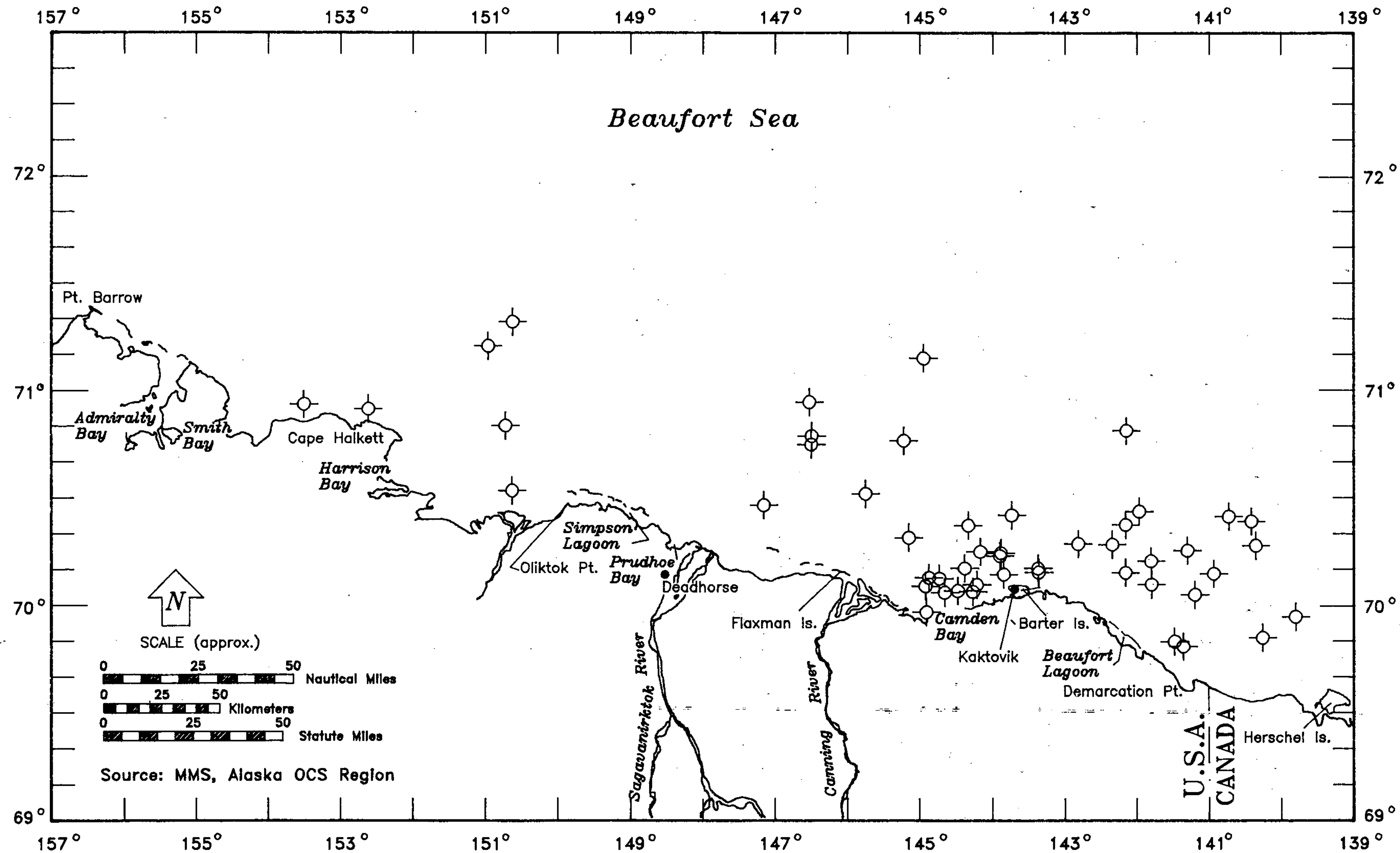


Figure 25. Map of Ringed Seal Sightings (-⌖-), September–October 1987

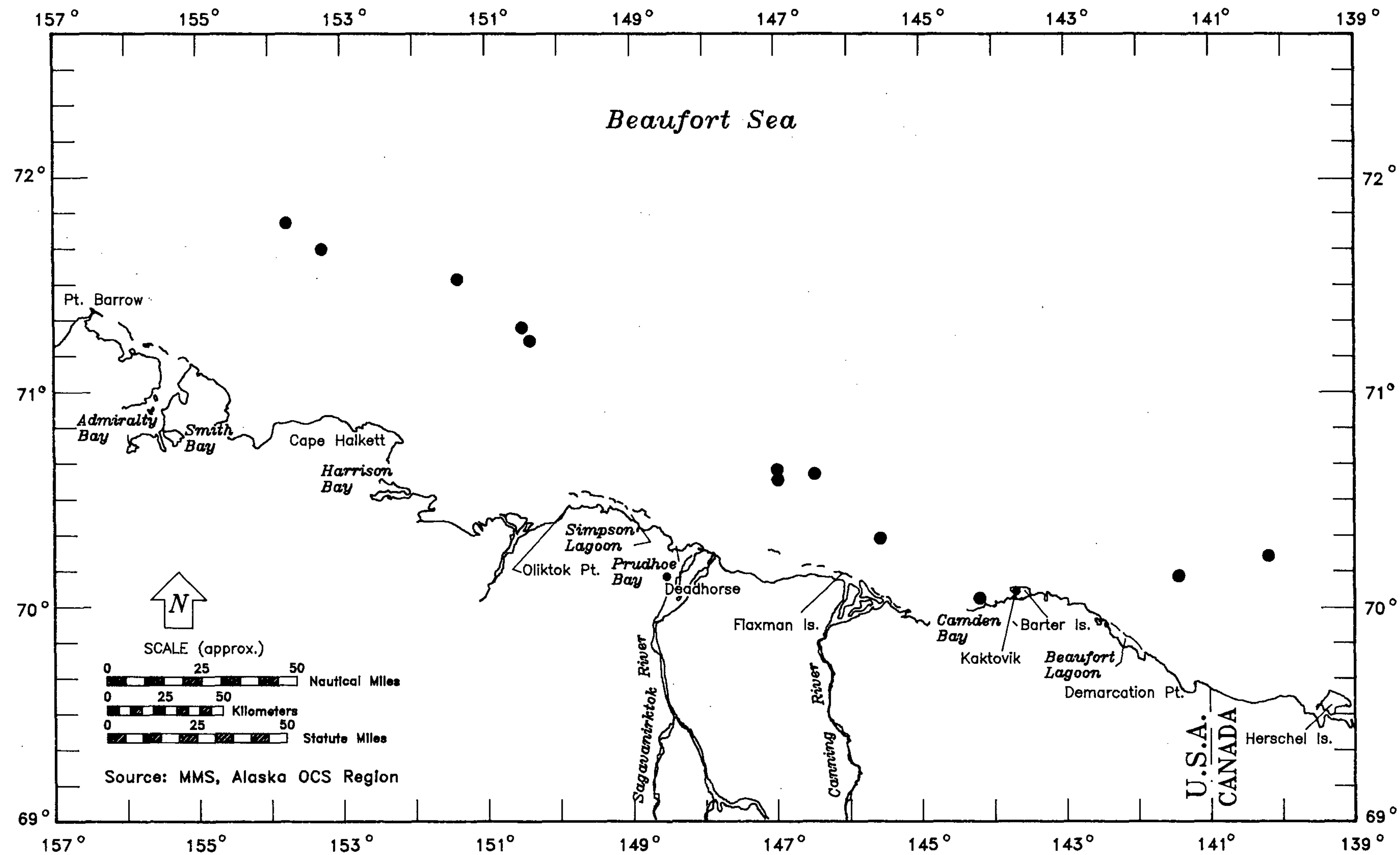


Figure 26. Map of Bearded Seal Sightings (●), September–October 1987

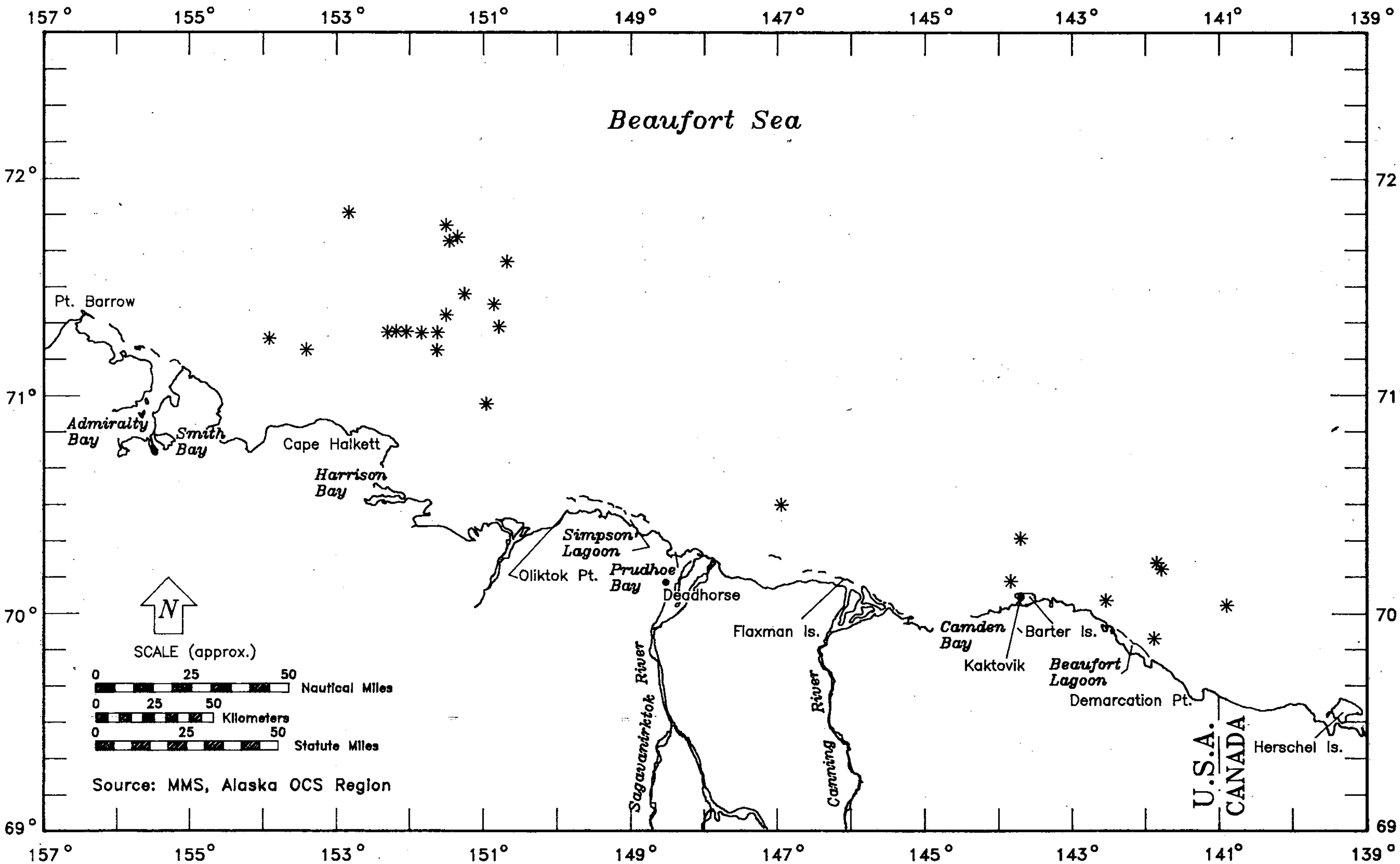


Figure 27. Map of Unidentified–Pinniped Sightings (✱), September–October 1987

IV. DISCUSSION

A. General Comparisons with Previous Surveys (1979-1986)

Results of the present study are generally within the range of result values from previous MMS-funded endangered whale surveys conducted during the fall (September-October) in the Beaufort Sea (Ljungblad et al., 1987). Fall ice conditions varied annually but can be categorized as having either predominantly heavy (70-90%) or light (0-30%) cover for most years. In heavy-ice years (1980, 1983), ice cover remained heavy throughout the fall season. In light-ice years (1979, 1981, 1982, 1984, 1986, and 1987), ice cover in the Alaskan Beaufort Sea was relatively heavy through August, becoming light through September, with freezeup commencing in early to mid-October. In 1987, ice conditions were extremely light, with the ice edge remaining farther offshore than normal and freezeup occurring later in October than usual. In 1985, ice conditions were intermediate to other years; average ice cover varied between 30 and 70 percent for most of August and September.

The relative abundance (WPUE) of bowhead whales in each survey area during both September and October 1987 was within the range of values observed for the years 1979 to 1986 (Table 12) and within 1 standard deviation (SD) of the mean value for previous years (1979-1986) in each area.

The percentage of bowhead whales engaged in "swimming" behavior in 1987 (71%) was the highest noted for this behavioral category (previous high = 68% in 1986). The cumulative 1979-1986 percentage (September-October) for swimming bowheads was 42 percent.

The ratio of bowhead calves for 1987 (0.01) was considered low compared to most 1979-1986 fall (September-October) surveys (overall estimate = 0.03), although similar to the 1981 and 1984 ratios (both = 0.01).

The total number of ringed seals for the 1987 survey (285) was the highest number noted on the 1982-1986 MMS-funded arctic whale surveys (previous high = 121 in 1986). The mean number of ringed seals observed (September-October) between 1982 and 1986 was 53 (SD = 51.3).

IV

B. Median Water Depth at Bowhead Sightings (1982-1987)

Of the 37 bowhead whales seen on line transects in Regions B, C', and D' during September to October 1987, the median water depth at the sightings was 31 m (Table 13). This depth, which was within the range of similar median values for Regions B, C', and D' in previous years, was considered typical of median values for the years 1982, 1984, 1985, and 1986. Thus, the data suggest that the position of the migration corridor did not change in 1987.

The only statistically significant difference between the median water depth for 1987 and previous years occurred between the value for 1987 and the value for 1983 (Table 14). Analysis by region showed that this difference was statistically significant only east of 150°W. longitude in Regions C' and D' (Table 14). Similar significant differences were noted between the 1983 median value and medians for all other years tested using the Mann-Whitney U

Table 12

Bowhead Whale Relative Abundance (WPUE) by Beaufort Sea Survey Block during September and October, 1979-1987 (after Ljungblad et al., 1987)

Year	Survey Block 1	2	3	4	5	6	7	8	9	10	11	Canada[1/]	Unblocked[2/]
SEPTEMBER													
1979	0.08	0.00	0.00	0.09	10.08	0.73	0.00	3/	3/	3/	3/	3/	3/
1980	0.38	0.00	0.00	0.47	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.47	3/
1981	0.22	0.00	0.00	6.13	6.20	0.00	0.00	0.00	0.00	3/	0.00	0.32	0.00
1982	6.83	1.35	0.80	0.93	11.30	0.00	0.00	0.00	1.28	3/	0.00	48.65	0.00
1983	0.11	0.87	0.61	0.00	0.00	1.51	1.90	0.00	0.36	0.21	0.53	3/	0.00
1984	0.59	1.05	0.18	2.69	3.19	1.94	0.00	0.00	0.00	0.00	0.00	17.00	0.00
1985	0.54	0.00	0.00	2.21	1.74	0.39	0.00	0.00	0.00	0.00	0.00	6.52	0.00
1986	0.10	0.00	0.00	0.94	2.36	0.29	0.10	0.00	0.00	0.00	0.45	7.98	0.00
1987	0.74	0.00	0.00	1.32	0.72	0.31	0.00	3/	0.00	3/	0.00	0.66	0.00
ALL YEARS	0.80	0.50	0.32	1.85	3.94	0.71	0.25	0.00	0.38	0.12	0.37	4.69	0.00
OCTOBER													
1979	1.58	0.00	3.67	2.35	3/	0.00	3/	3/	3/	3/	0.00	3/	0.00
1980	0.10	1.18	0.35	0.29	0.00	0.00	3/	3/	3/	0.00	0.00	0.00	0.00
1981	0.89	0.00	0.52	4.22	0.00	0.00	0.00	3/	3/	3/	0.00	3/	3/
1982	0.19	0.00	2.48	0.00	0.70	0.00	3/	0.00	0.00	0.00	0.19	0.46	0.00
1983	0.00	0.00	0.49	0.00	0.00	0.27	2.17	3/	3/	0.00	0.00	3/	0.00
1984	0.29	0.26	1.24	0.00	1.37	0.00	3/	3/	3/	0.00	3.05	3.70	0.00
1985	2.26	0.00	0.40	0.00	0.00	0.00	0.00	0.00	3/	0.00	9.00	0.00	0.00
1986	1.00	0.38	0.47	0.71	3/	0.00	3/	3/	0.00	0.00	0.00	3/	0.00
1987	0.19	0.00	2.94	0.62	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ALL YEARS	0.96	0.25	1.18	1.11	0.32	0.06	0.65	0.00	0.00	0.00	1.42	0.87	0.00

Source: MMS, Alaska OCS Region.

1/ Canadian waters east of 140°W. longitude.
2/ Values in this column are based on survey effort in Alaskan arctic waters outside established survey blocks.
3/ No surveys conducted.

Table 13

Central-Tendency Statistics for Water Depth (in meters) at Random Sightings (SI) of Bowhead Whales (September-October) in Regions B, C', and D', by Year and Region

Year	Region	SI 1/	Median	CI 2/	Mean	SD 3/	Range
1982	B	8	17	13-342	99.0	146.21	13-342
	C'	30	29	22-38	30.3	9.42	11-51
	D'	5	40	4/	43.2	11.12	29-59
All	3	43	31	22-38	44.6	65.96	11-342
1983	B	9	64	4/	363.2	747.02	24-2,323
	C'	5	1,289	4/	945.0	858.85	53-2,021
	D'	9	640	4/	972.7	766.06	49-1,902
All	3	23	347	53-1,646	728.1	800.06	24-2,323
1984	B	15	44	27-60	52.1	41.43	11-77
	C'	9	40	15-64	38.9	16.16	15-64
	D'	14	45	22-274	90.3	129.98	22-485
All	3	38	44	27-55	62.8	84.36	11-485
1985	B	3	183	4/	183.0	159.02	24-342
	C'	9	31	20-38	31.0	6.58	20-38
	D'	1	4/	4/	4/	4/	64
All	3	13	33	24-183	68.6	92.61	20-342
1986	B	4	19	4/	52.0	69.11	13-155
	C'	12	22	11-40	64.5	143.59	9-519
	D'	22	34	24-46	33.9	13.60	9-57
All	3	38	28	18-42	45.4	82.60	9-519
1987	B	4	19	4/	19.5	3.42	16-24
	C'	9	27	15-37	26.8	7.46	15-37
	D'	24	38	27-55	45.8	42.00	18-234
All	3	37	31	26-38	38.3	35.35	15-234
CUMULATIVE STATISTICS							
1982-1987	B	43	32	20-44	136.0	394.20	11-2,323
	C'	74	31	26-38	98.0	310.51	9-2,021
	D'	75	42	37-49	163.8	400.20	9-1,902
All	3	192	37	29-40	130.7	356.49	9-2,323

Source: MMS, Alaska OCS Region.

1/ SI = random sightings.
2/ CI = confidence interval.
3/ SD = standard deviation.
4/ Insufficient sample size.

Table 14

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

REGION B	1982	1983	1984	1985	1986
1983	$U = 56$ $p<0.10$				
1984	$U = 82$ $p<0.20$	$U' = 92$ $p<0.20$			
1985	$U' = 14$ $p\leq 0.50$	$U = 17$ $p\leq 0.50$	$U' = 23$ $p\leq 0.50$		
1986	$U = 15$ $p\leq 0.50$	$U = 28$ $p\leq 0.20$	$U = 44$ $p\leq 0.50$	$U = 7$ $p\leq 0.50$	
1987	$U = 18$ $p<0.50$	$U' = 29$ $p<0.20$	$U' = 47$ $p<0.20$	$U = 9$ $p<0.20$	$U = 10$ $p<0.20$

REGION C'	1982	1983	1984	1985	1986
1983	$U = 150$ $p<0.001$				
1984	$U = 182$ $p<0.50$	$U = 43$ $p\leq 0.005$			
1985	$U = 142$ $p<0.50$	$U = 45$ $p\leq 0.001$	$U = 54$ $p<0.50$		
1986	$U' = 224$ $p<0.50$	$U = 58$ $p\leq 0.002$	$U = 78$ $p = 0.10$	$U = 66$ $p<0.50$	
1987	$U' = 162$ $p<0.50$	$U = 45$ $p\leq 0.001$	$U = 58$ $p<0.20$	$U = 54$ $p<0.50$	$U = 58$ $p<0.50$

Table 14

Interyear Correlation (nonparametric) of the Median Water Depths at Random Bowhead Whale Sightings (September-October), Using the Mann-Whitney U Test
(Continued)

REGION D'	1982	1983	1984	1985	1986
1983	U'= 44 p≤0.002				
1984	U'= 37 p<0.50	U = 118 p<0.001			
1985	U = 5 1/	U'= 8 p<0.50	U = 11 p<0.50		
1986	U = 78 p<0.20	U = 196 p<0.001	U = 212 p<0.10	U = 22 p≤0.20	
1987	U = 78 p<0.50	U = 296 p<0.001	U = 203 p<0.50	U = 23 p<0.20	U'= 331 Z = 1.19 p<0.50

ALL THREE REGIONS (COMBINED)	1982	1983	1984	1985	1986
1983	U = 856 Z = 4.36 p<0.001				
1984	U = 1,217 Z = 2.81 p<0.01	U = 738 Z = 4.96 p<0.001			
1985	U = 311 p<0.50	U' = 212 p<0.002	U = 287 Z = 1.01 p<0.50		
1986	U'= 931 Z = 1.40 p<0.50	U = 931 p<0.001	U = 1,250 Z = 1.69 p<0.20	U = 3.66 Z = 0.71 p<0.50	
1987	U = 796 Z = 0.68 p<0.50	U = 884 Z = 5.13 p<0.001	U = 758 Z = 1.81 p<0.10	U = 232 p<0.50	U = 773 Z = 1.17 p<0.50

Source: MMS, Alaska OCS Region.

1/ Insufficient sample size.

Test (Zar, 1984) for nonparametric comparisons. The 1983 median (347 m) appears to be a uniquely aberrant value (Table 13). The reason for the offshore (deep-water) migratory route in 1983 is not fully understood. Heavy ice cover and the possible indirect effect of such ice on prey availability has been postulated as a causative factor (Ljungblad et al., 1987).

Mean water depths also were calculated for Regions B, C', and D' (Table 13). Mean values were considered less descriptive of the migration "axis" and more susceptible to bias caused by feeding whales than were median values. It is notable, however, that the mean values for 1987 were lower than means for the years 1982 through 1986 in both Regions B and C'. Comparison of the means using the Tukey Test (Zar, 1984) confirmed that 1983 was unique among other years in the spatial distribution of the fall bowhead migration. Differences between mean values for 1983 and some of the other years (including 1987) were considered highly significant in Regions C' and D', thus mirroring differences noted between median values in those regions (Table 15).

NOTE: The 234-m maximum depth indicated in Table 13 is at great variance with the 79-m maximum depth shown in Table 8. The discrepancy is the result of the shelf break occurring within a small geographic segment (defined by the DEPTH program) for which a single average depth value was assigned. The 234-m value, which was derived visually from a bathymetric map, is the more accurate maximum depth.

C. Potential Responses of Bowheads to Survey Aircraft

During the first half of October, there were four sightings of 12 bowhead whales for which responses to the survey aircraft were observed (Table 16). Although it was not possible to determine if observed responses resulted directly from overflight by survey aircraft, sudden overt changes in whale behavior were noted. Responses included abrupt dives, course diversion, or cessation of behavior ongoing at first sighting. There was no statistically significant difference ($t' = 0.613$, $p<0.50$) between the mean altitudes of the survey aircraft when potential responses were observed ($\bar{x} = 1{,}074$, $SD = 484$) or were not observed ($\bar{x} = 1{,}162$, $SD = 318$).

D. Management Use of 1987 Field Information

During 1987, MMS issued eight permits to industry for seismic exploration in the Beaufort Sea. Only six of these permits were used between 24 July and 26 October, primarily in the eastern Beaufort Sea. In order to prevent potential operational effects on subsistence whaling, the permittees followed stringent restrictions--including a provision to stop seismic operations when whales were visible from the vessel--as the bowhead whale migration progressed through the area of operations. Daily summaries of survey information were transferred from the field to Anchorage for use by MMS Resource Evaluation and by NMFS in implementing areawide permit restrictions on high-energy seismic operations during periods of limited visibility.

On 13 September 1987, Tenneco Oil Company emplaced a Single Steel Drilling Caisson (SSDC) (Fig. 28) at 70°06.6'N. latitude, 142°47.1'W. longitude--east of Barter Island at the Aurora drilling site. The main body of the structure is approximately 162 m long, 53 m wide, and 25 m high. The SSDC rests on a subsurface MAT that permits drilling in water depths of 9 to 23 m without

Table 15

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

REGION B
ANOVA F = 2.1, $p<0.50$

Tukey Test:	(1987)	(1986)	(1984)	(1982)	(1985)	(1983)
	19.5	52.0	52.1	99.0	183.0	363.2

REGION C'
ANOVA F = 16.5, p< <0.001

Tukey Test:	(1987)	(1982)	(1985)	(1984)	(1986)	(1983)
	26.8	30.3	31.0	38.9	64.5	945.0

($p<0.001$)

REGION D'
ANOVA F = 18.5, p< <0.001

Tukey Test:	(1986)	(1982)	(1987)	(1985)	(1984)	(1983)
	33.9	43.2	46.8	64.0	90.3	972.7

($p<0.05$)

($p<0.001$)

ALL THREE REGIONS (COMBINED)
ANOVA F = 18.1, p< <0.001

Tukey Test:	(1987)	(1982)	(1986)	(1984)	(1985)	(1983)
	38.3	44.6	45.4	62.8	68.6	728.1

($p<0.001$)

Source: MMS, Alaska OCS Region.

Table 16

Semimonthly Summary of Bowhead Whales Potentially Responding to Survey Aircraft (Fall 1987)

Potential Response Observed	1-15 Sep No. (%)	16-30 Sep No. (%)	1-15 Oct No. (%)	16-31 Oct No. (%)	Total No. (%)
Yes	0	0	12 (26)	0	12 (11)
No	13 (100)	40 (85)	35 (74)	3 (100)	91 (83)
Unknown	0	7 (15)	0	0	7 (6)
TOTAL	13 (100)	47 (100)	47 (100)	3 (100)	110 (100)

Source: MMS, Alaska OCS Region.

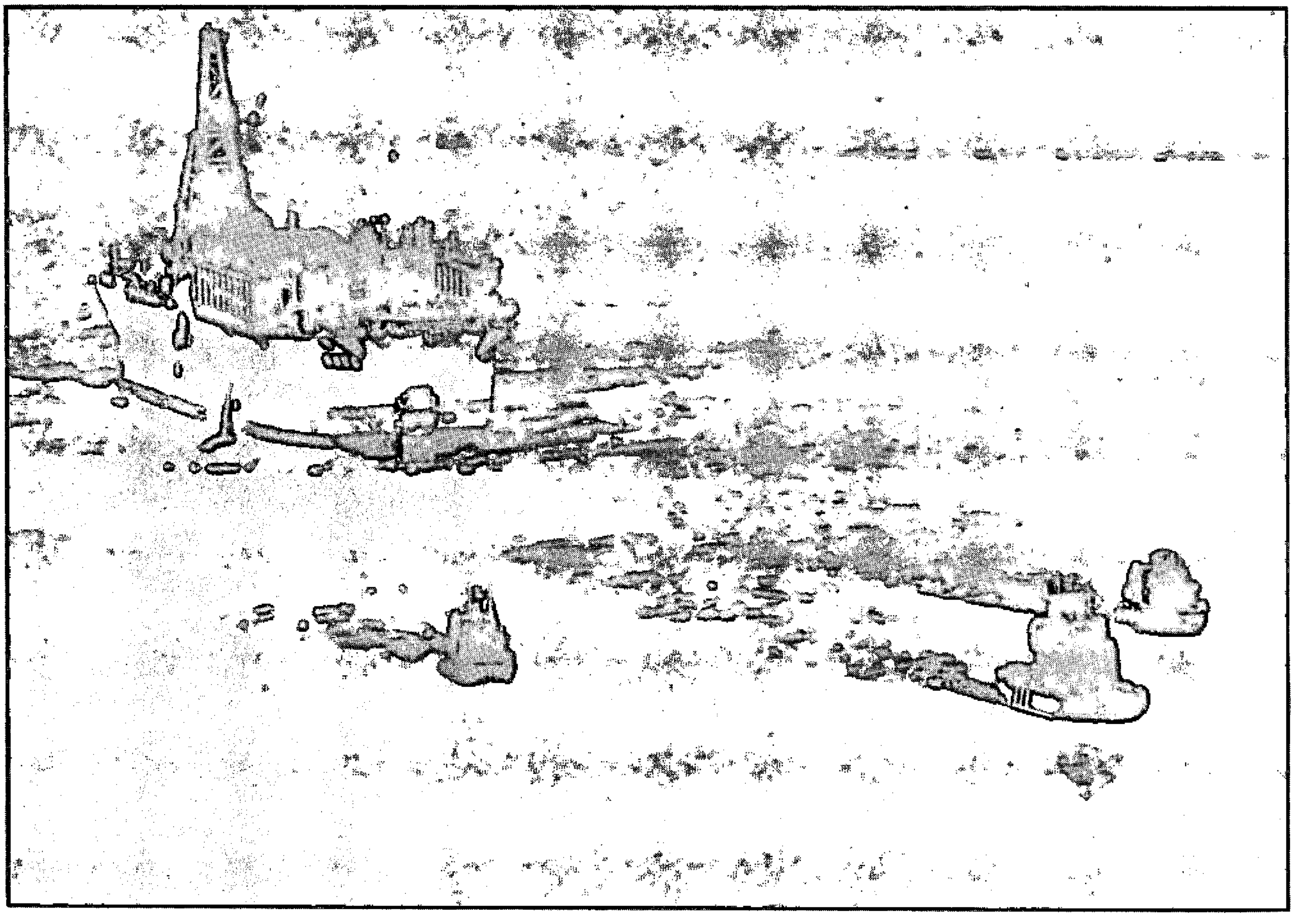


Figure 28. SSDC Under Tow to Drill Site East of Barter Island (11 September 1987)

bottom preparation. The MAT has a seafloor dimension of 162 m by 110 m and is 13 m high, excluding a system of skirts that penetrates the seabed.

Bowheads seen in the general vicinity of the SSDC are shown for each bimonthly period of the Fall-1987 survey (Figs. 16 through 19). The closest sighting of a bowhead whale was noted on 28 October 1987 (Appendix C: Flight 38) at a distance of 9.3 km from the nonoperational drilling structure. This was the only bowhead within 10 km of the SSDC; and its behavior appeared normal, i.e., it was swimming at moderate speed on a 240° heading (magnetic).

In order to determine with high resolution the number of whales in the immediate area of the SSDC, two systematic survey grids with parallel transect lines 4 km apart were conducted on 20 September and 13 October (Appendix B: Flights 15 and 33). On 20 September no whales were observed in the immediate area of the SSDC with a survey-grid pattern permitting up to 100-percent survey coverage. Four sightings of six bowhead whales were made on 13 October. These systematic grid surveys are included as search surveys (rather than random transects) in all other summaries and analyses in this report.

Based on daily summaries of survey information provided by the Fall-1987 study and on subsequent management decisions made by MMS Field Operations and NMFS relative to the end of the bowhead migration, the SSDC well in this location was not spudded until 2 November 1987.

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APPENDIX A

LIST OF TABLES AND FIGURES

Figures

Tables

BOWHEAD WHALE DENSITIES

This appendix presents an analysis of bowhead whale densities in the Beaufort Sea for the period September through October 1987.

A. Study Area

Density estimates were calculated for survey blocks previously shown for the Beaufort Sea (Fig. 1).

The Beaufort Sea study area was divided into four regions from west to east (Fig. A-1). Region A extended from 157°00'W. to 153°30'W., Region B from 153°30'W. to 150°00'W., Region C from 150°00'W. to 146°00'W., and Region D from 146°00'W. to 141°00'W. Depth contours of 10, 50, 200, and 2,000 m were used to stratify the Beaufort Sea from north to south. The stratum from the coastline to 10 m corresponded closely to the area inside the barrier islands (A1, B1, C1, D1A, and D1B). The shelf (10- to 200-m) and offshelf (200- to >2,000-m) areas were stratified from 10 to 20 m, 20 to 50 m, 50 to 200 m, 200 to 2,000 m, and deeper than 2,000 m. Areas A2, B2, C2, D2A, and D2B corresponded to the 10-m to 20-m strata; areas A3, B3, C3, and D3 corresponded to the 20-m to 50-m strata, and so on (Fig. A-1).

B. Data Analysis

Density estimates were calculated using strip-transect methodologies. Such estimates require that the sightings be made on transect legs (i.e., that sightings be random) and that they occur within a predetermined distance from the aircraft (Hayne, 1949). Therefore, although abundance was calculated for any block in which bowheads were seen, density was calculated only for survey blocks and bathymetric regions in which whales were seen within 1 km on either side of the aircraft while on a transect leg. The basic formula for strip-transect estimators (Hayne, 1949) is:

$$N = \frac{nA}{2\,LH}$$

where N is the estimated animal population, n is the number of individuals counted, A is the area of strip, L is the transect length, and H is the mean sighting distance. The basic assumptions for use of this formula, and the degree to which these assumptions were met in the Fall-1987 and previous MMS-funded arctic whale surveys, are incorporated by reference (Ljungblad et al., 1987: Appendix B).

Maps were prepared using the computer program AMP (A Mapping Package), consisting of FORTRAN subroutines that can be used for customized plotting applications. The AMP was used to plot aerial-survey data on file as a series of geographic coordinates (latitude and longitude) associated with time and sightings of whales. Landmasses are part of the AMP database. Depth contours were plotted by reading a separate file of data points prepared for this analysis. Depth contours were digitized using several reference maps as described by Ljungblad et al. (1987: Appendix B).

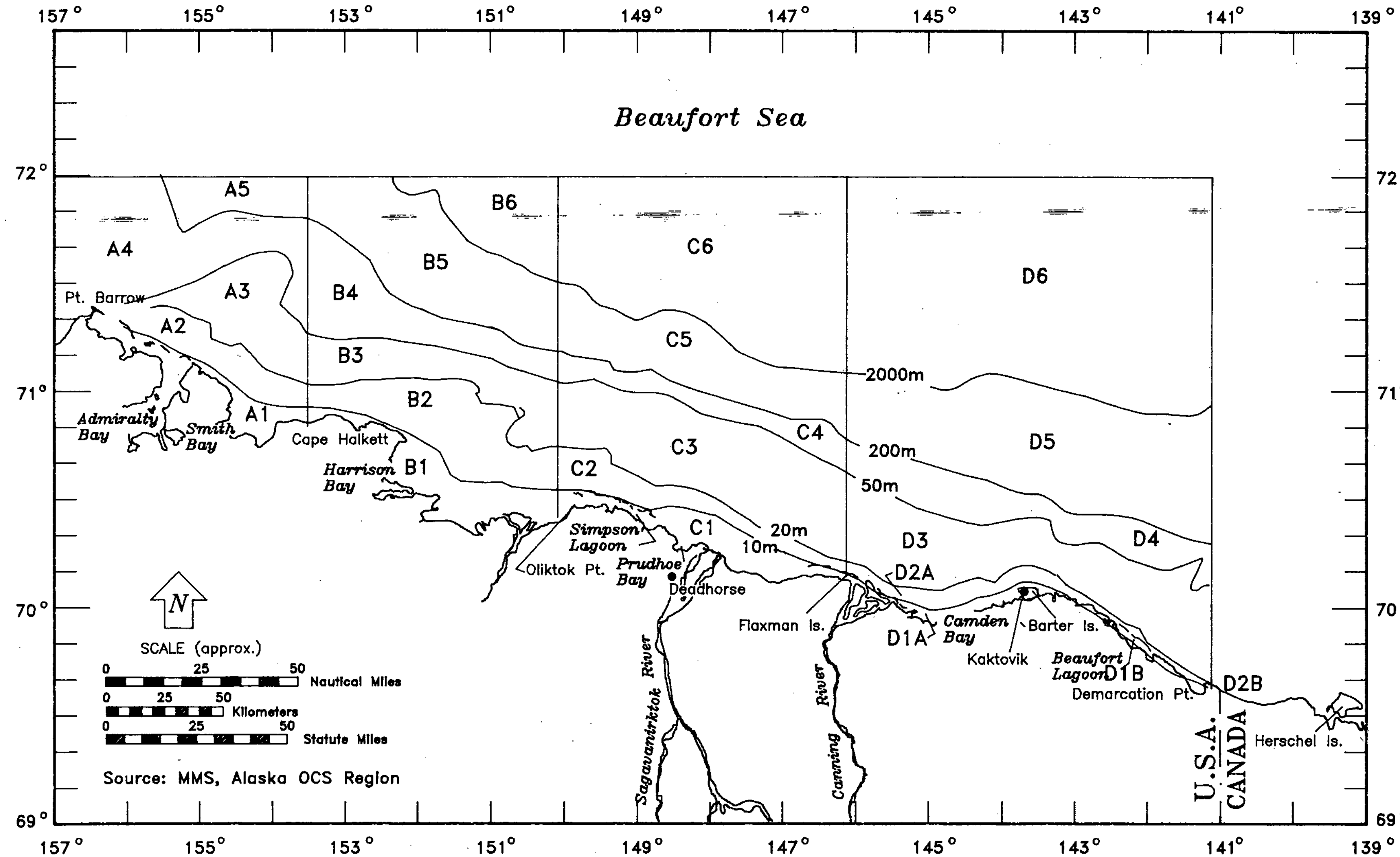


Figure A–1. Four Regions of the Alaskan Beaufort Sea Stratified by Bathymetric Subregions

A computer program (SPEED) developed for previous surveys was utilized to screen for unlikely data values and to check the chronological order of time. Aerial-survey-data files were screened for obvious errors in geographic position by separately plotting the course of each daily aerial survey. A computer program was used to evaluate flight speeds and distances on a point-to-point basis, and listings of these values were scanned for suspiciously slow or fast speeds. The listings and maps were compared, errors were flagged and edited, and the process was repeated until data files were error-free with respect to these conditions.

The tracing of region boundaries with a digitizer led to a boundary problem termed "splinter error." The problem was discussed in a previous survey report (Ljungblad et al., 1987); however, the implications of the "splinter error" are small in relation to this study. The statistics reported for each subregion and region and the total study area are valid; but there may be small discrepancies when the values of subregions are summed and compared to the values reported for larger regions (e.g., number of survey hours flown, listed in the tables as survey time).

C. Statistics Presented in Tables

1. Region Area (km²): Areas were approximated by straight-line integration, which contributed to discrepancies between the summation of subregion areas and areas calculated for larger regions. Area calculations are accurate to within about 1 percent of the true area.

2. Percent of Total Area: The percent of total area was calculated as the region area divided by the sum of all subregion areas; this quantity was then multiplied by 100.

3. Percent of Area Surveyed: The percent of area surveyed is a relative measure of survey effort expended per survey region. Strip width was defined as 2 km (i.e., 1 km on either side of the aircraft). Therefore, the total number of kilometers flown equaled half the number of square kilometers surveyed. The percent of total area was calculated as the number of square kilometers surveyed divided by the region area; this quantity was then multiplied by 100.

This technique did not account for overlapping aerial-survey strips, which result in double counting the area surveyed. Therefore, some areas surveyed may show more than 100-percent coverage.

4. Transect Time (h:min): This is the time in hours and minutes spent surveying an area. Because of splinter errors and rounding errors, the values reported for time spent surveying subregions did not always equal those reported for larger regions.

5. Percent of Total Time: This is the time in hours and minutes spent surveying a region divided by the sum of survey times reported for each subregion.

6. Number of Transects Flown: Transects or flight legs were defined as units of survey effort by the aerial-survey team. The beginnings and endings of transects were further defined by the survey-region boundaries. A portion

of an aerial-survey leg passing over a region was treated as a transect relative to that region. Thus, one transect could be broken into several transects with respect to subregion analyses. For this reason, the sum of the transects based on subregions was greater than the total number of transects reported for the total region.

7. Number of Bowheads Observed: This indicates the number of bowhead whales observed within 1 km of either side of the aircraft.

8. Density as Number per km², Variance, and Confidence Interval: Calculation of density statistics for each stratum followed the method employed by Krogman et al. (1979), which was based on the strip-transect technique described in Estes and Gilbert (1978):

$$\hat{R} = \Sigma y_i / \Sigma x_i \qquad \text{(A-1)}$$

where $\hat{R}$ = observed density of whales per km²
y_i = number of whales observed in the ith strip transect
x_i = area of the ith strip transect

$$S^2_{\hat{R}} = [\Sigma(y_i{}^2/x_i) - R\Sigma y_i]/(n-1)(\Sigma x_i) \qquad \text{(A-2)}$$

where $S^2_{\hat{R}}$ = variance of R
n = number of strip transects

$$CI = \hat{R} \pm t_{0.05}(2)V\sqrt{V(\hat{R})} \qquad \text{(A-3)}$$

The notation $t_{0.05}(2)V$ refers to the critical value of t, where alpha (α) = 0.05 based on a two-tailed test with V degrees of freedom. Degrees of freedom were calculated as the total number of transects minus 1.

D. Results

Densities by survey block were estimated as the number of bowhead whales per 100 km² (Table A-1).

During the first half of September, over 10 percent of the area in each block was surveyed for Blocks 2, 5, 6, 7, and 11. Of these, bowheads were observed within 1 km of the transect line in Blocks 5 and 6, for estimated densities of 0.11 and 0.08 whales, respectively, per 100 km².

During the second half of September, over 10 percent of the area in each block was surveyed for Blocks 1, 4, 5, and 11. Of these, bowheads were observed within 1 km of the transect line in Blocks 1, 4, and 5, for estimated densities of 0.29, 0.19, and 0.18 whales, respectively, per 100 km².

During the first half of October, over 10 percent of the area in each block was surveyed for Blocks 3, 4, and 11. Of these, bowheads were observed within

Table A-1

Semimonthly Estimates of Bowhead Whale Densities, Fall 1987, by Survey Block (strip width = 2 km)

Block Number (by Semimonthly Period)	Block Area (km^2)	Transect Distance (km)	Percent of Area Surveyed	Transect Time (h)	Percent of Total Time	No. of Transects Flown	No. of Whales Observed	Density (No./100km^2)
1-15 Sep								
1	10,222	449	8.79	1.88	11.26	20	2	0.22
2	6,672	474	14.22	2.02	12.07	8	0	0.00
3	11,475	59	1.02	0.20	0.93	4	0	0.00
4	5,714	104	3.65	0.45	2.72	7	0	0.00
5	9,481	1,750	36.92	7.86	47.05	30	4	0.11
6	8,109	612	15.10	2.64	15.80	10	1	0.08
7	8,109	451	11.11	1.80	10.78	12	0	0.00
9	9,753	14	0.29	0.05	0.33	1	0	0.00
11	10,358	580	11.19	2.25	10.38	9	0	0.00
16-30 Sep								
1	10,222	861	16.85	3.45	22.35	19	5	0.29
2	6,672	1	0.04	0.00	0.03	2	0	0.00
3	11,475	276	4.99	1.11	7.16	1	0	0.00
4	5,714	1,062	37.17	4.82	31.28	26	4	0.19
5	9,481	1,092	23.05	4.80	31.16	17	4	0.18
6	8,109	301	7.43	1.23	8.01	10	0	0.00
7	8,109	1	0.03	0.01	0.03	2	0	0.00
11	10,358	571	11.03	2.37	8.71	9	0	0.00

Table A-1

Semimonthly Estimates of Bowhead Whale Densities, Fall 1987, by Survey Block (strip width = 2 km) (Continued)

Block Number (by Semimonthly Period)	Block Area (km^2)	Transect Distance (km)	Percent of Area Surveyed	Transect Time (h)	Percent of Total Time	No. of Transects Flown	No. of Whales Observed	Density (No./100 km^2)
1-15 Oct								
1	10,222	477	9.33	2.04	14.83	15	0	0.00
2	6,672	75	2.24	0.29	2.12	4	0	0.00
3	11,475	1,200	20.92	5.07	39.02	22	10	0.42
4	5,714	735	25.71	3.05	22.16	17	0	0.00
5	9,481	278	5.87	1.13	8.23	4	0	0.00
6	8,109	80	1.96	0.33	2.42	7	0	0.00
7	8,109	367	9.04	1.50	10.93	6	0	0.00
8	9,753	3	.06	0.01	0.09	3	0	0.00
11	10,358	544	10.52	2.21	15.47	16	0	0.00
16-31 Oct								
3	11,475	125	2.18	0.52	2.12	4	0	0.00
4	5,714	276	9.66	1.21	4.91	9	0	0.00
5	9,481	1,730	36.48	7.03	28.60	28	0	0.00
6	8,109	120	2.95	0.46	1.87	6	0	0.00
7	8,109	50	1.24	0.19	0.78	9	0	0.00
11	10,358	90	1.75	0.38	1.53	2	0	0.00

Source: MMS, Alaska OCS Region.

1 km of the transect line only in Block 3, for an estimated density of 0.42 whales per 100 km².

During the last half of October, over 10 percent of the area in each block was surveyed only for Block 5. No bowheads were observed within 1 km of the transect line during this period, for an estimated density in Block 5 of 0.00 whales.

Densities of bowhead whales per 100 km² also were estimated for the bathymetric subregions shown in Figure A-1.

During September, over 10 percent of the area in each subregion was surveyed for Subregions B_4, B_5, B_6, C_2, C_3, C_4, C_5, D_{1A}, D_{2A}, D_{2B}, D_3, D_4, and D_5 (Table A-2). Of these, bowheads were observed within 1 km of the transect line in Subregions C_2, C_3, D_3, D_4, and D_5, for estimated densities of 0.659, 0.220, 0.099, 0.318, and 0.051, respectively. The highest densities in September were in Subregion C_2 (0.659), located between the 10-m and 20-m isobaths, and Subregion D_4 (0.318), located between the 50-m and 200-m isobaths in the eastern portion of the Alaskan Beaufort Sea.

During October, over 10 percent of the area in each subregion was surveyed for Subregions B_1, B_2, B_3, B_4, B_5, B_6, C_3, D_{2A}, D_{2B}, and D_3, (Table A-3). Of these, bowheads were observed within 1 km of the transect line only in Subregions B_2 and B_3, for estimated densities of 0.565 and 0.729, respectively. These relatively high densities were located in 10 to 50 m of water between 150°00'W. and 153°30'W. longitudes.

E. Discussion

High densities noted for Subregions C_2 (0.659) and D_4 (0.318) in September 1987 were by far the highest estimated for these subregions in the month of September for the years 1979 through 1986 (Ljungblad et al., 1987: Appendix B).

The high density noted for Subregion B_2 (0.565) in October 1987 was by far the highest estimated for this subregion in the month of October for the years 1979 through 1986 (Ljungblad et al., 1987: Appendix B). The high density noted for Subregion B_3 (0.729) was exceeded in October 1979 (1.898) and in October 1982 (2.405).

F. Literature Cited

Estes, J.A. and J.R. Gilbert. 1978. Evaluation of an Aerial Survey of Pacific Walruses (*Odobenus rosmarus divergens*). J. Fish. Res. Board Can. 35:1130-1140.

Hayne, D.W. 1949. An Examination of the Strip Census Method for Estimating Animal Populations. J. Wildl. Mgt. 13:145-147.

Krogman, B.D., H.W. Braham, R.M. Sonntag, and R.G. Punsley. 1979. Early Spring Distribution, Density, and Abundance of the Pacific Walrus (*Odobenus rosmarus*) in 1976. Outer Continental Shelf Environmental Assessment Program, Final Report of Principal Investigators No. R7120804, Research Unit 14.

Table A-2

Bowhead Whale Density Estimates for Bathymetric Subregions
in the Alaskan Beaufort Sea, September 1987
(strip width = 2 km)

Region Name	Region Area (km^2)	Percent of Total Area	Percent of Area Surveyed	Transect Time (h:min)	Percent Total Survey Time	No. of Transects Flown	No. of Whales Observed	Density (No./100 km^2)	Variance (10^{-4})	Confidence Range of Density
A	13,360	13.20	0.00	00:00	0.00	0	0	0.000	0.0000	0
A1	2,361	2.33	0.00	00:00	0.00	0	0	0.000	0.0000	0
A2	1,648	1.63	0.00	00:00	0.00	0	0	0.000	0.0000	0
A3	2,688	2.65	0.00	00:00	0.00	0	0	0.000	0.0000	0
A4	5,166	5.10	0.00	00:00	0.00	0	0	0.000	0.0000	0
A5	1,497	1.48	0.00	00:00	0.00	0	0	0.000	0.0000	0
B	19,593	19.35	13.25	05:09	16.30	53	0	0.000	0.0000	0
B1	2,614	2.58	3.49	00:10	0.53	4	0	0.000	0.0000	0
B2	3,814	3.77	6.57	00:29	1.53	5	0	0.000	0.0000	0
B3	2,739	2.71	6.42	00:21	1.10	5	0	0.000	0.0000	0
B4	3,061	3.02	16.29	01:02	3.26	13	0	0.000	0.0000	0
B5	5,009	4.95	21.46	02:06	6.65	16	0	0.000	0.0000	0
B6	2,357	2.33	21.44	01:01	3.23	10	0	0.000	0.0000	0
C	27,156	26.82	13.15	07:23	23.35	92	7	0.196	0.0111	0-0.406
C1	2,086	2.06	1.07	00:03	0.16	4	0	0.000	0.0000	0
C2	1,809	1.79	16.77	00:39	2.04	20	2	0.659	0.4316	0-2.034
C3	6,482	6.40	35.12	04:40	14.78	38	5	0.220	0.0122	0-0.444
C4	1,803	1.78	15.35	00:32	1.67	13	0	0.000	0.0000	0
C5	4,252	4.20	10.83	00:58	3.06	9	0	0.000	0.0000	0
C6	10,724	10.59	2.16	00:31	1.64	8	0	0.000	0.0000	0

Table A-2

Bowhead Whale Density Estimates for Bathymetric Subregions
in the Alaskan Beaufort Sea, September 1987
(strip width = 2 km)
(Continued)

Region Name	Region Area (km^2)	Percent of Total Area	Percent of Area Surveyed	Transect Time (h:min)	Percent Total Survey Time	No. of Transects Flown	No. of Whales Observed	Density (No./100 km^2)	Variance (10^{-4})	Confidence Range of Density
D	41,139	40.63	20.94	19:04	60.35	255	10	0.116	0.0015	0.040-0.192
D1A	494	.49	11.50	00:08	0.42	12	0	0.000	0.0000	0
D1B	428	.42	3.66	00:02	0.11	7	0	0.000	0.0000	0
D2A	915	.90	46.36	00:59	3.12	22	0	0.000	0.0000	0
D2B	510	.50	43.38	00:31	1.64	28	0	0.000	0.0000	0
D3	6,933	6.85	58.40	08:59	28.42	65	4	0.099	0.0028	0-0.204
D4	3,462	3.42	45.43	03:39	11.55	63	5	0.318	0.0239	0.009-0.627
D5	9,785	9.66	20.03	04:06	12.97	43	1	0.051	0.0012	0-0.122
D6	18,612	18.38	1.70	00:40	2.12	15	0	0.000	0.0000	0
CUMULATIVE ESTIMATE										
	101,248	100.00	14.60	31:36	100.00	400	17	0.115	0.0012	0.040-0.190

Source: MMS, Alaska OCS Region.

Table A-3

Bowhead Whale Density Estimates for Bathymetric Subregions in the Alaskan Beaufort Sea, October 1987 (strip width = 2 km)

Region Name	Region Area (km^2)	Percent of Total Area	Percent of Area Surveyed	Transect Time (h:min)	Percent Total Survey Time	No. of Transects Flown	No. of Whales Observed	Density (No./100 km^2)	Variance (10^{-4})	Confidence Range of Density
A	13,360	13.20	1.62	00:26	2.90	9	0	0.000	0.0000	0
A1	2,361	2.33	3.07	00:10	1.12	4	0	0.000	0.0000	0
A2	1,648	1.63	3.32	00:06	0.66	3	0	0.000	0.0000	0
A3	2,688	2.65	3.32	00:10	1.12	2	0	0.000	0.0000	0
A4	5,166	5.10	0.00	00:00	0.00	0	0	0.000	0.0000	0
A5	1,497	1.48	0.00	00:00	0.00	0	0	0.000	0.0000	0
B	19,593	19.35	16.67	07:07	47.69	91	10	0.306	0.0356	0-0.615
B1	2,614	2.58	16.55	00:58	6.55	15	0	0.000	0.0000	0
B2	3,814	3.77	23.20	01:59	13.26	20	5	0.565	0.0957	0-1.205
B3	2,739	2.71	25.05	01:32	10.25	19	5	0.729	0.5176	0-2.202
B4	3,061	3.02	15.39	01:03	7.03	21	0	0.000	0.0000	0
B5	5,009	4.95	10.30	01:03	7.03	10	0	0.000	0.0000	0
B6	2,357	2.33	11.65	00:32	3.57	6	0	0.000	0.0000	0
C	27,156	26.82	4.06	02:21	15.74	34	0	0.000	0.0000	0
C1	2,086	2.06	.50	00:02	0.20	4	0	0.000	0.0000	0
C2	1,809	1.79	6.35	00:16	1.79	9	0	0.000	0.0000	0
C3	6,482	6.40	12.44	01:43	11.52	15	0	0.000	0.0000	0
C4	1,803	1.78	5.97	00:13	1.45	4	0	0.000	0.0000	0
C5	4,252	4.20	1.48	00:07	0.78	2	0	0.000	0.0000	0
C6	10,724	10.59	0.00	00:00	0.00	0	0	0.000	0.0000	0

Table A-3

Bowhead Whale Density Estimates for Bathymetric Subregions
in the Alaskan Beaufort Sea, September 1987
(strip width = 2 km)
(Continued)

Region Name	Region Area (km^2)	Percent of Total Area	Percent of Area Surveyed	Transect Time (h:min)	Percent Total Survey Time	No. of Transects Flown	No. of Whales Observed	Density (No./100 km^2)	Variance (10^{-4})	Confidence Range of Density
D	41,139	40.63	7.11	05:02	33.67	73	0	0.000	0.0000	0
D1A	494	.49	2.35	00:01	0.11	4	0	0.000	0.0000	0
D1B	428	.42	7.66	00:01	0.11	3	0	0.000	0.0000	0
D2A	915	.90	28.43	00:32	3.57	15	0	0.000	0.0000	0
D2B	510	.50	23.12	00:03	0.33	4	0	0.000	0.0000	0
D3	6,933	6.85	23.21	02:34	17.21	21	0	0.000	0.0000	0
D4	3,462	3.42	7.74	00:33	3.63	14	0	0.000	0.0000	0
D5	9,785	9.66	4.60	00:54	6.03	8	0	0.000	0.0000	0
D6	18,612	18.38	.94	00:24	2.68	4	0	0.000	0.0000	0
CUMULATIVE ESTIMATE										
	101,248	100.00	7.42	14:56	100.00	207	10	0.133	0.0059	0-0.303

Source: MMS, Alaska OCS Region.

Ljungblad, D.K., S.E. Moore, J.T. Clarke, and J.C. Bennett. 1987. Distribution, Abundance, Behavior and Bioacoustics of Endangered Whales in the Alaskan Beaufort and Eastern Chukchi Seas, 1979-86. OCS Study MMS 87-0039. NOSC Technical Report 1177 prepared for USDOI, MMS, Alaska OCS Region, 391 pp.

DAILY FLIGHT SUMMARIES - TWIN OTTER

This appendix consists of Flight Tracks 1 through 36, depicting aerial surveys flown over the study area between 1 September and 15 October 1987, by MMS personnel aboard a Twin Otter aircraft. Maps for Appendices B and C were prepared using a series of computer programs consisting of BASIC subroutines implemented on a Hewlett-Packard (HP 85) microcomputer connected to an HP 7470A printer/plotter. The coastlines for each map, digitized on an HP 9111A graphics tablet, were formatted to examine the principal study area. As a result, a comparison of flight tracks can be made on a visual basis over the period of the field season to evaluate ongoing patterns of the animal distribution and aircraft coverage. Each map shows the flight track as a line drawn through position updates recorded on the aircraft computer system. Each animal sighting is marked with a species symbol on the flight-track plot. The symbols used can be keyed out to a two-letter abbreviation shown in each map legend representing the following species:

BH = Bowhead Whale
BE = Beluga Whale
BS = Bearded Seal
RS = Ringed Seal
PN = Unidentified Pinniped

Summary information on bowhead whale sightings is presented beneath the flight caption in a tabular format, as follows:

T#/C# Total number of whales/total number of calves seen

LAT/LONG Location (latitude N./longitude W.) in degrees, minutes, and tenths of minutes

DIS Perpendicular distance from the aircraft in meters (altitude x cotangent clinometer angle)

CUE Sighting cue:

BO = Body	MP = Mud Plumes
BW = Blow	DY = Display
SP = Splash	

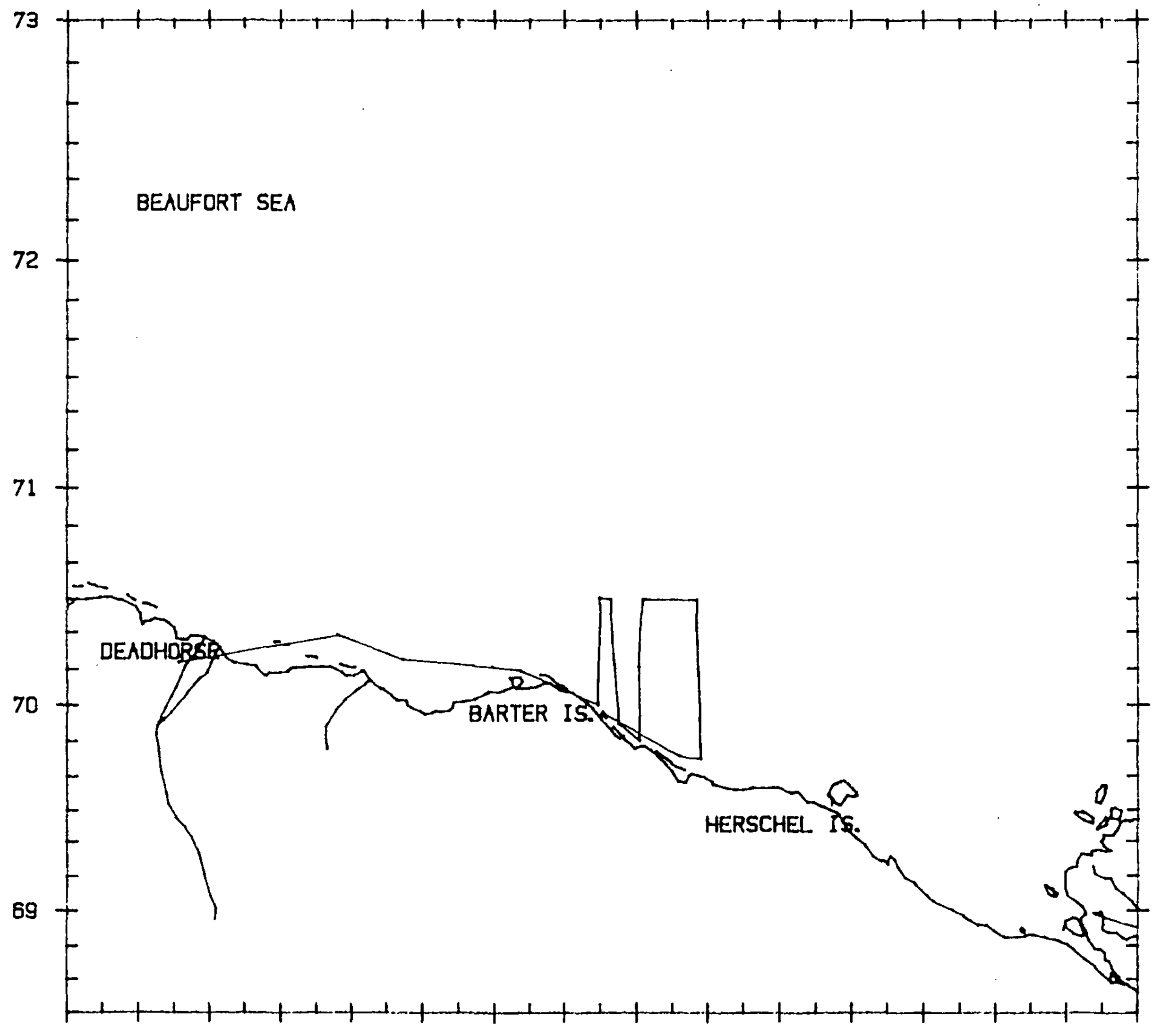
BEH Behavior:

SW = Swim	DY = Display	SH = Spy-Hop
DI = Dive	MT = Mate	TS = Tail-Slap
RE = Rest	FE = Feed	BR = Breach
MI = Mill	CC = Cow-Calf	RL = Roll
UB = Underwater Blow	DE = Dead	NA = None

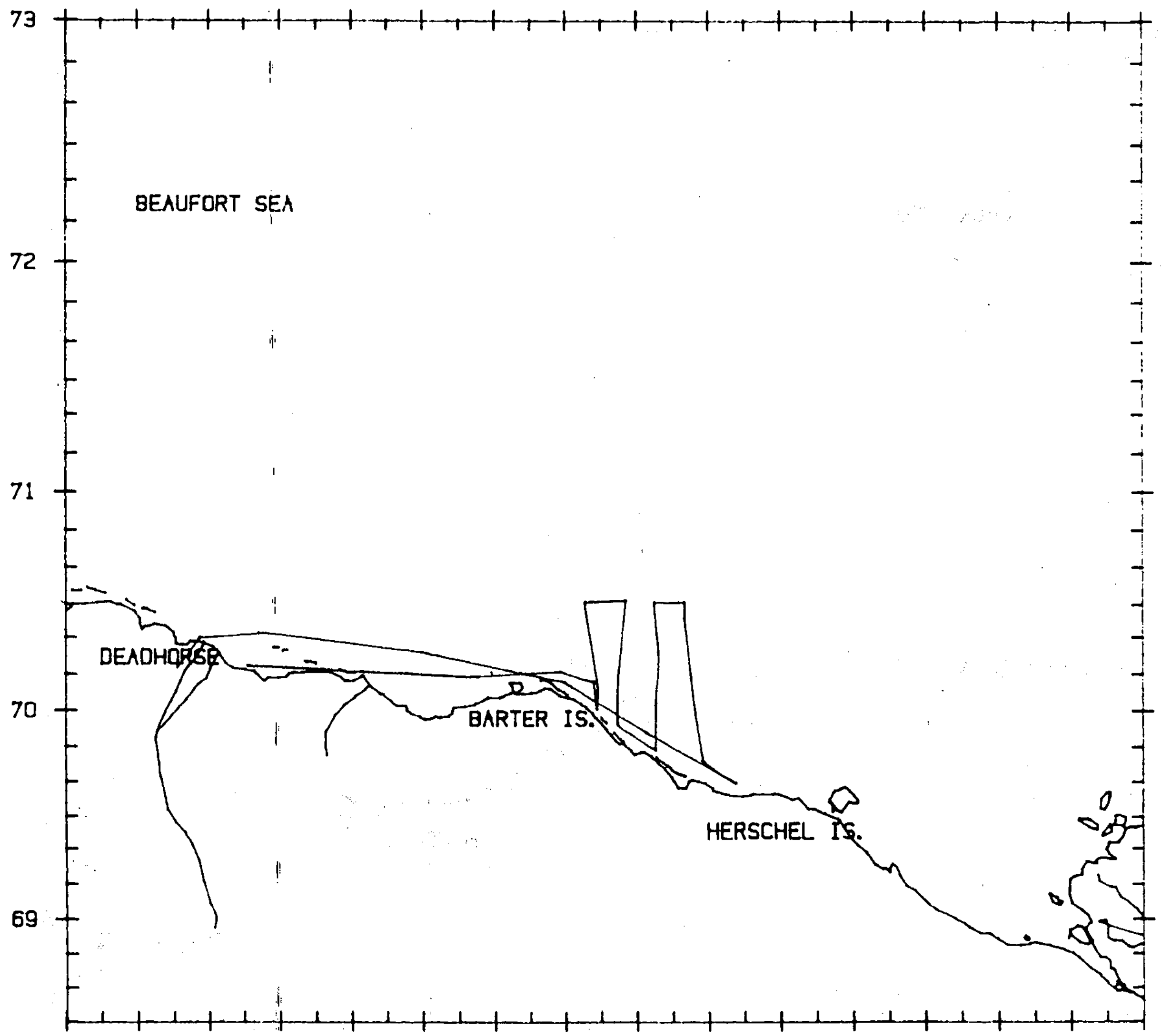
HDG Heading in magnetic degrees

ICE	Ice cover in percent
SS	Sea state (Beaufort scale)
DEPTH	Depth in meters
Dash (-)	Indicates data were not recorded

TWIN OTTER FLIGHT 1: 2 September 1987



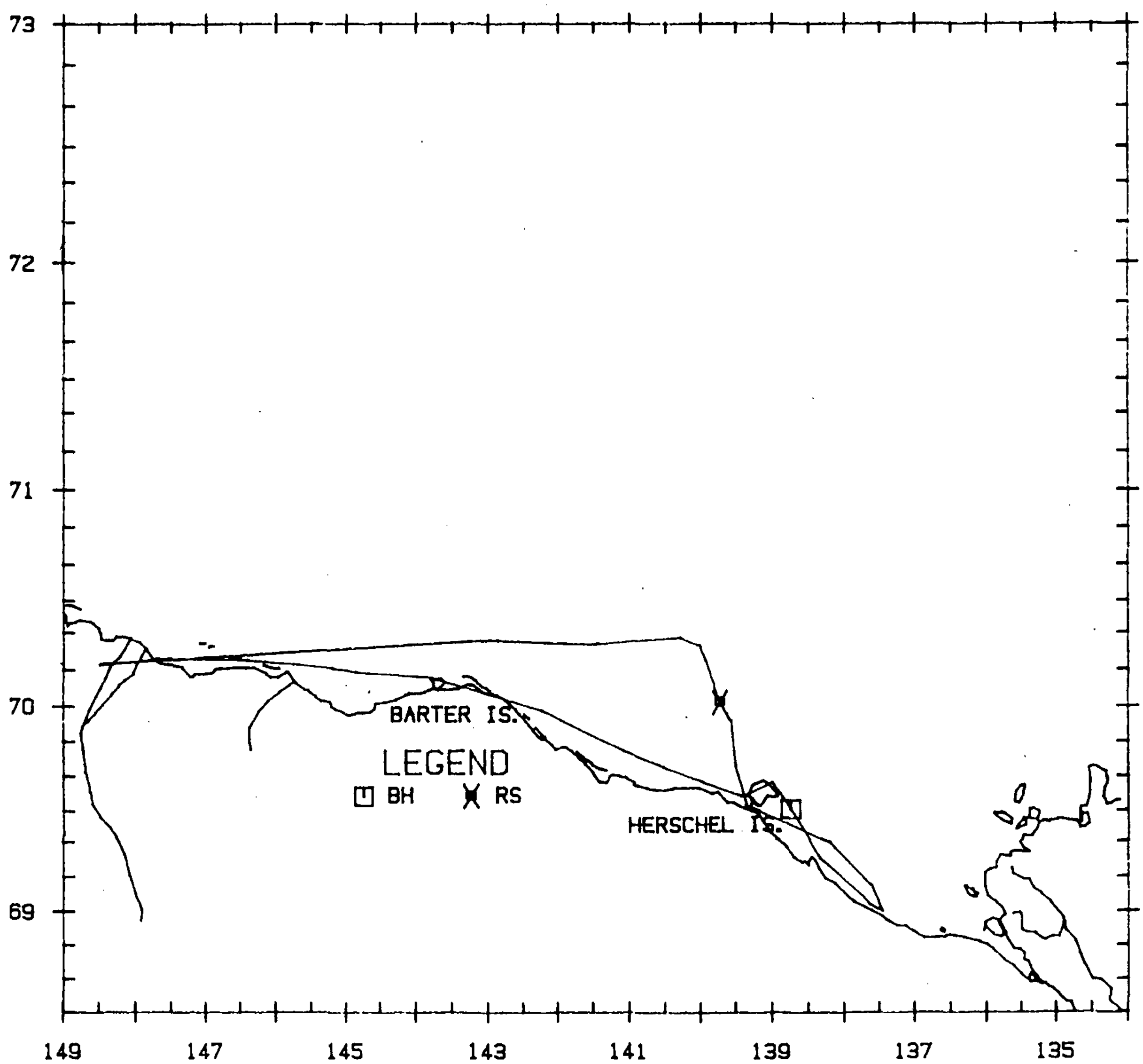
TWIN OTTER FLIGHT 2: 5 September 1987



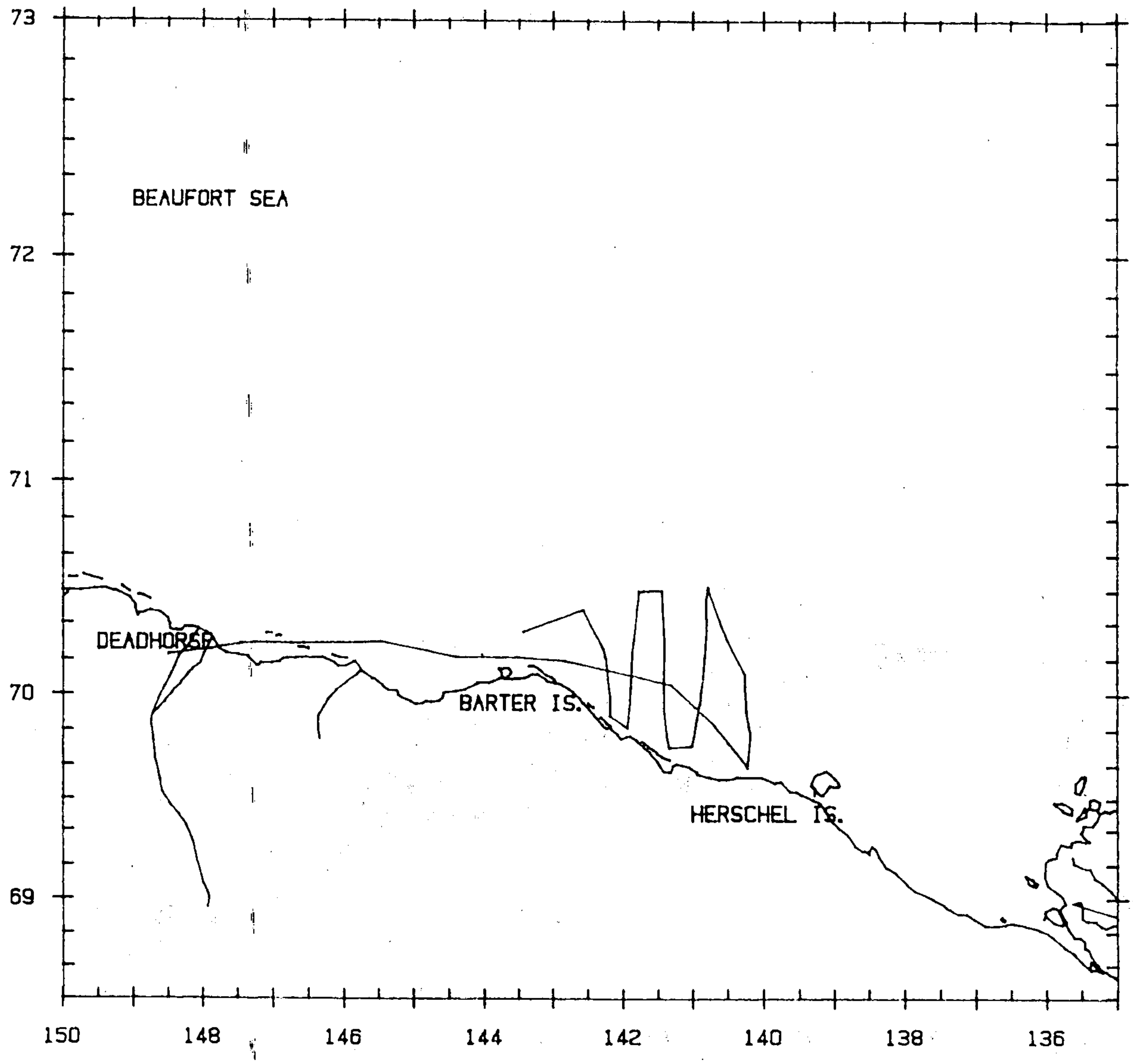
TWIN OTTER FLIGHT 3: 6 September 1987

Bowhead Whales

T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	69°29.1'	138°45.0'	168	BO	SW	225	0	B3	26



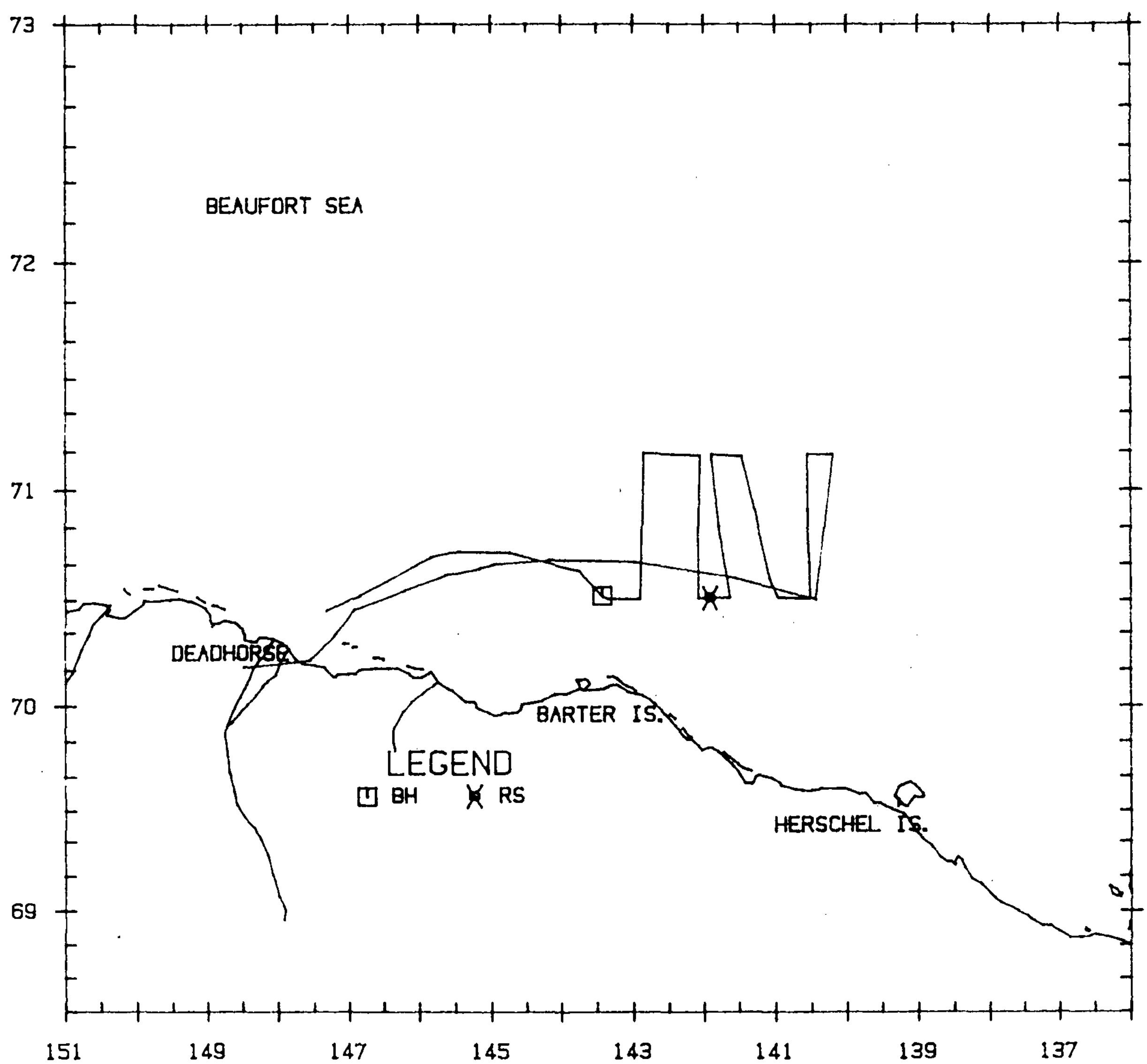
TWIN OTTER FLIGHT 4: 8 September 1987



TWIN OTTER FLIGHT 5: 9 September 1987

Bowhead Whale

T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	70°31.5'	143°25.9'	80	BW	SW	270	0	B3	53

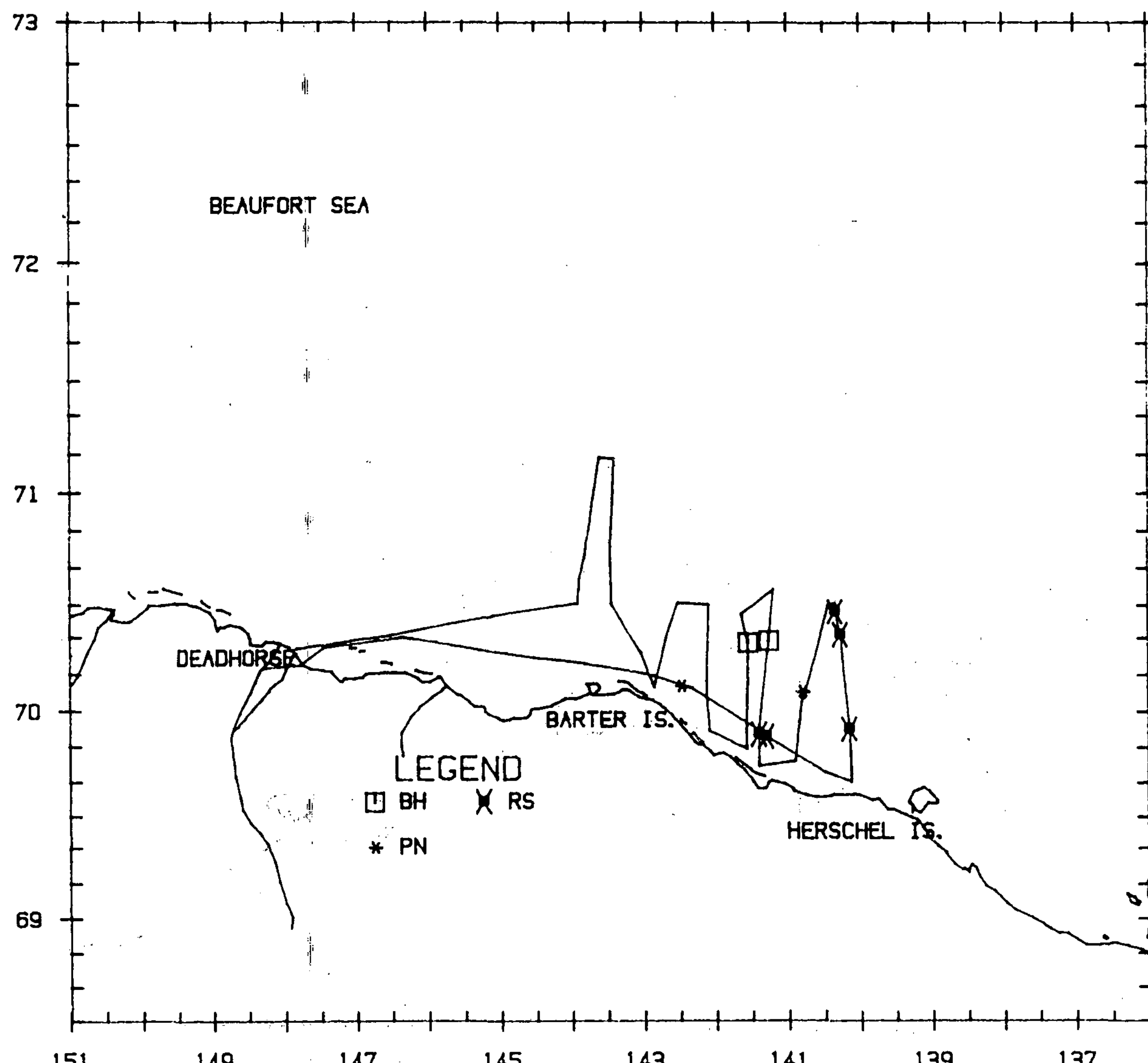


TWIN OTTER FLIGHT 6: 10 September 1987

Bowhead Whales

T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	70°19.3'	141°16.1'	1314	BW	SW	270	0	B3	53

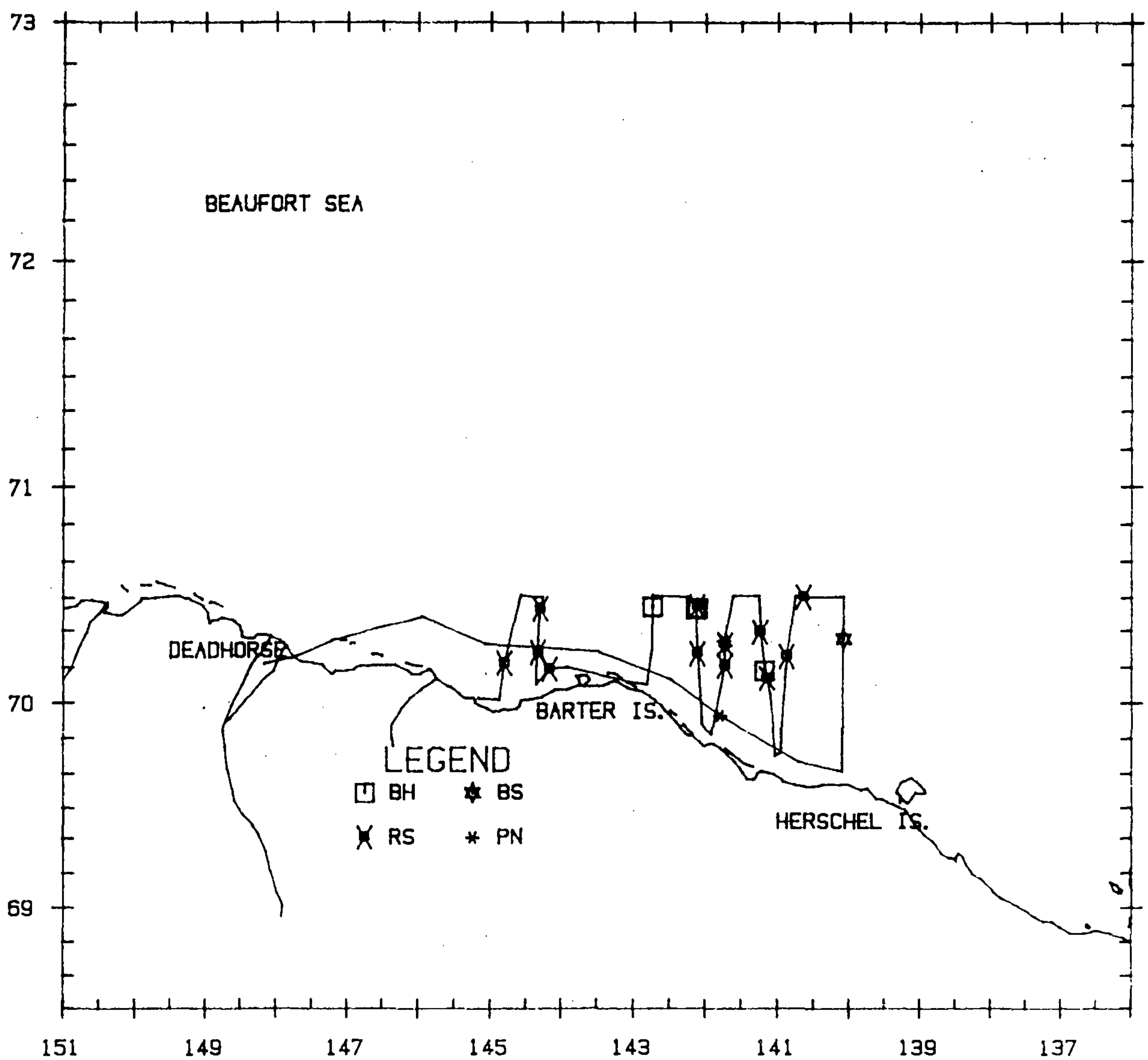
Bowheads shown on this map represent separate sightings at the same whale.



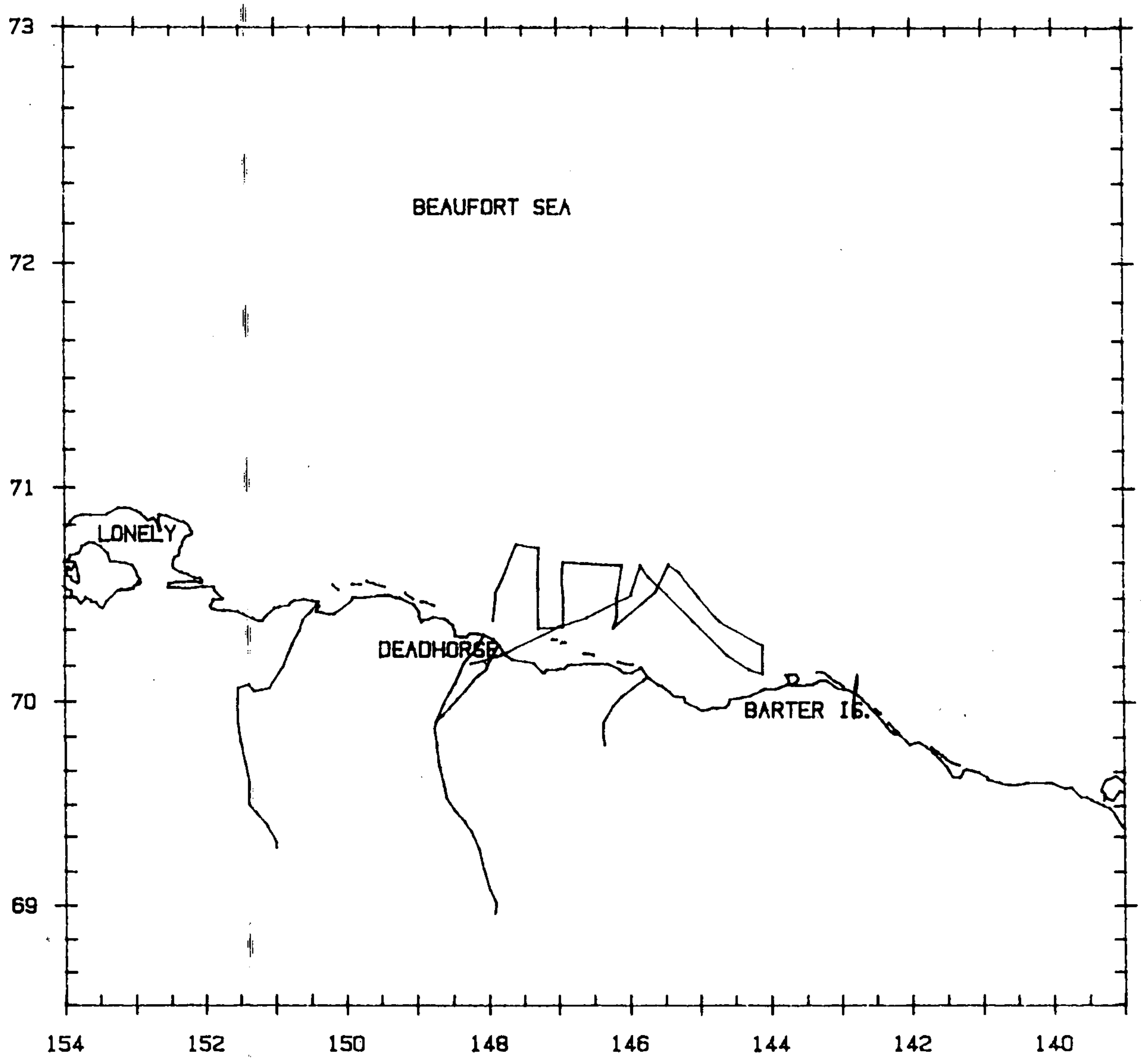
TWIN OTTER FLIGHT 7: 11 September 1987

Bowhead Whales

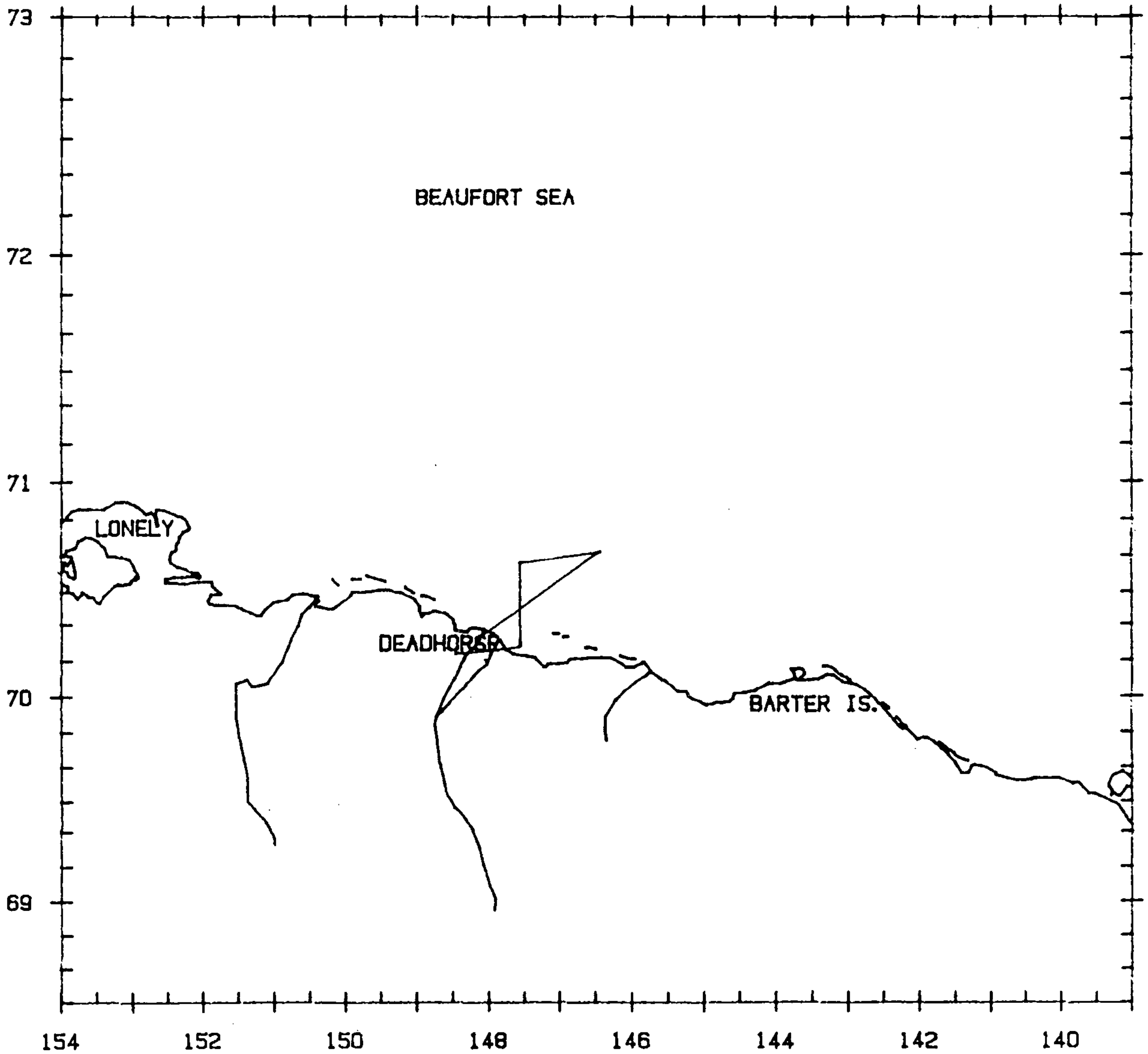
T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	70°09.0'	141°10.9'	774	BO	MI	-	0	B2	49
1/0	70°25.6'	142°08.6'	647	SP	SW	265	0	B2	49
1/0	70°25.9'	142°06.5'	-	BO	SW	240	0	B2	49
1/0	70°26.2'	142°44.6'	1071	BO	SW	90	0	B2	46
2/0	70°26.4'	142°44.5'	683	BO	SW	270	0	B2	46



TWIN OTTER FLIGHT 8: 12 September 1987



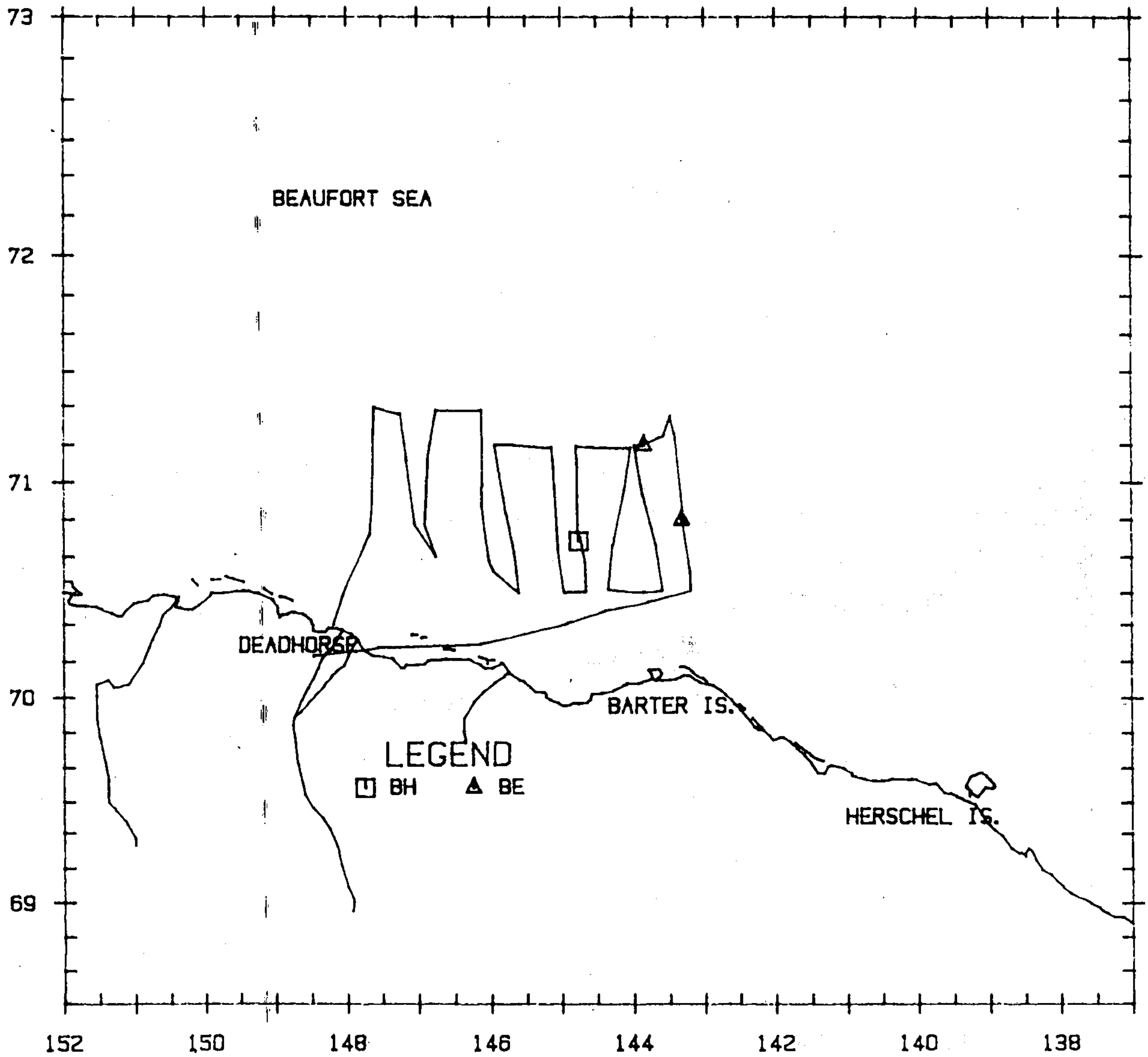
TWIN OTTER FLIGHT 9: 13 September 1987



TWIN OTTER FLIGHT 10: 14 September 1987

Bowhead Whales

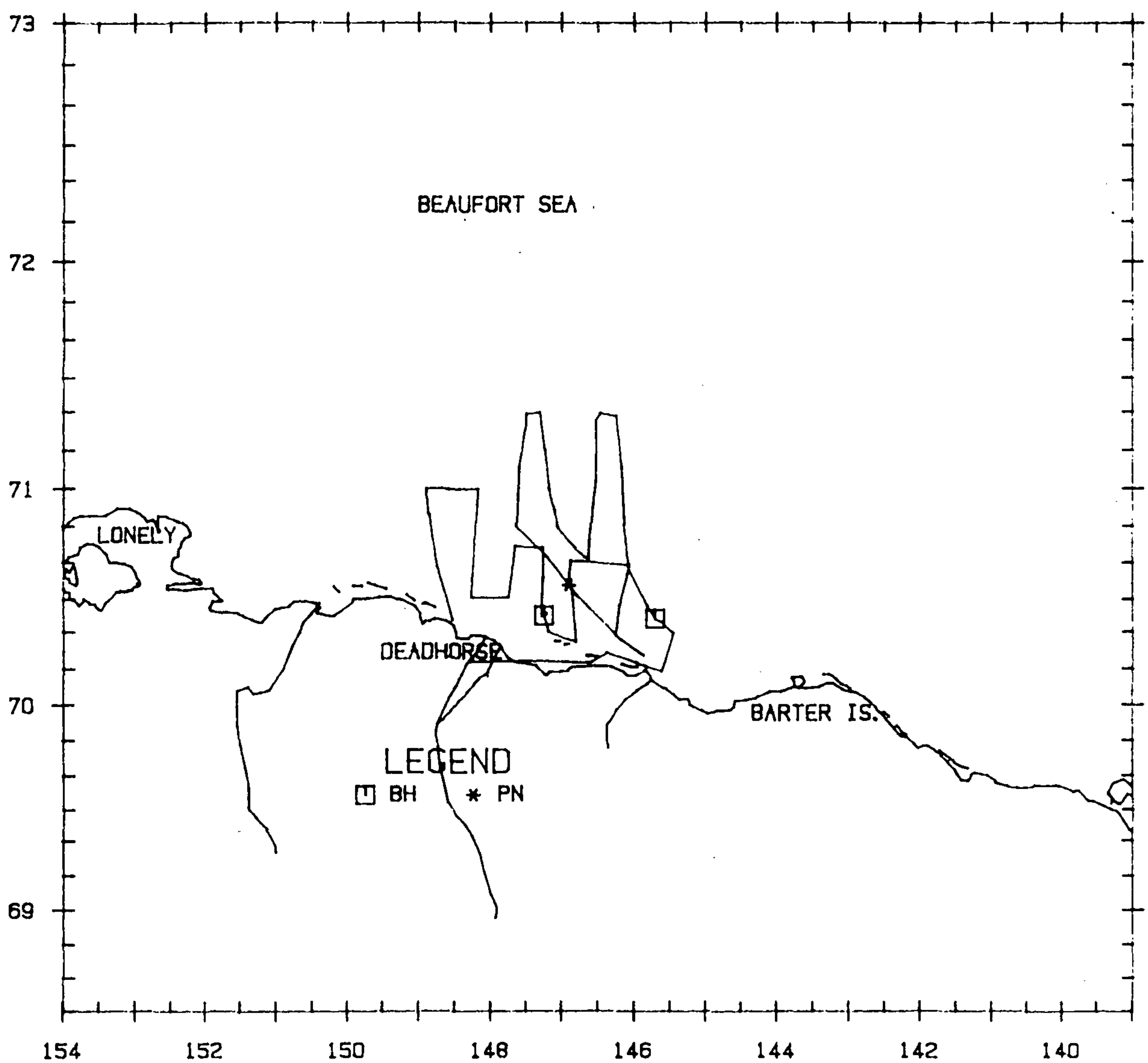
T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	70°44.3'	144°45.2'	863	BO	SW	350	10	B3	79



TWIN OTTER FLIGHT 11: 15 September 1987

Bowhead Whales

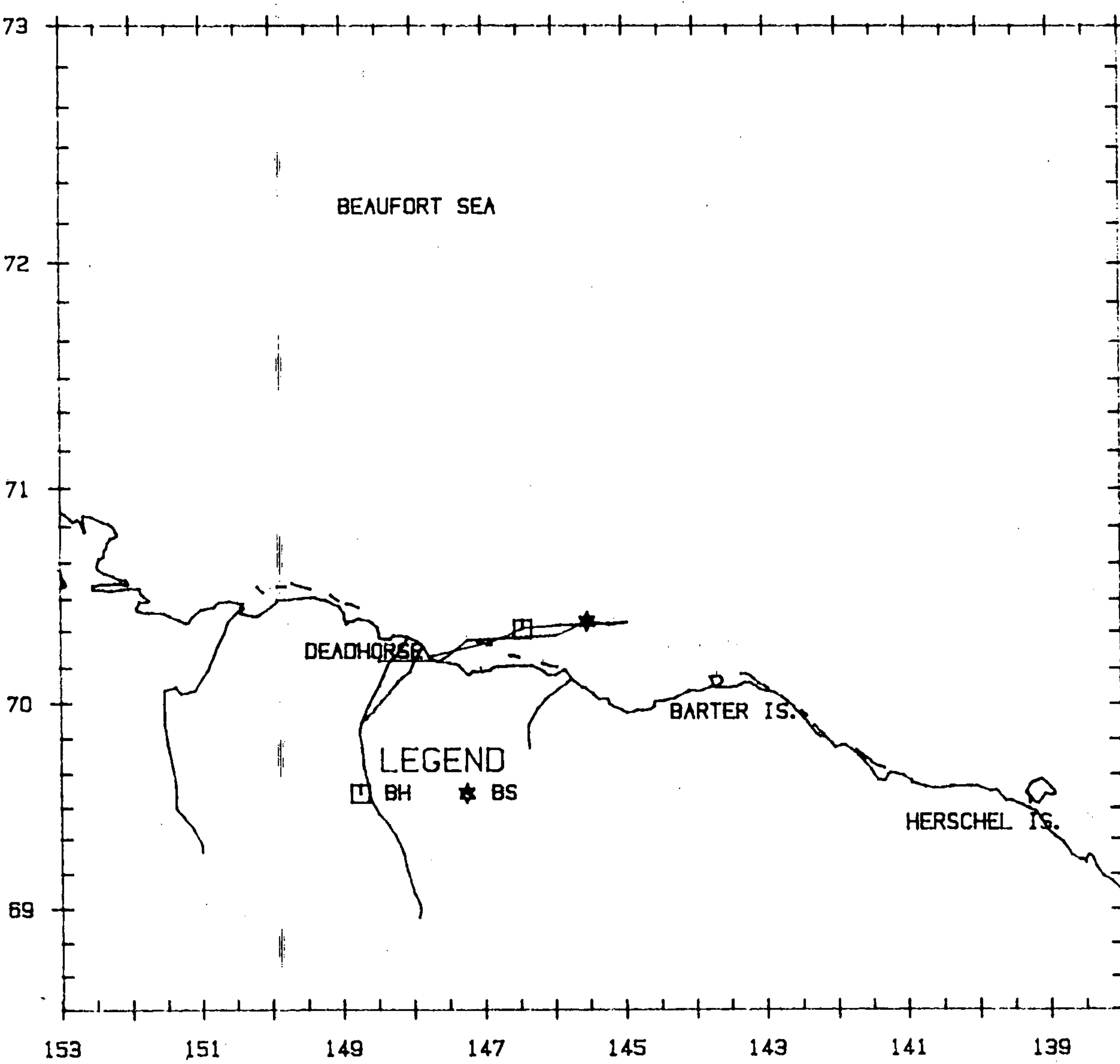
T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	70°23.5'	145°42.2'	-	BO	SW	360	2	B3	26
2/0	70°24.3'	147°14.7'	395	BO	SW	270	0	B3	13



TWIN OTTER FLIGHT 12: 16 September 1987

Bowhead Whales

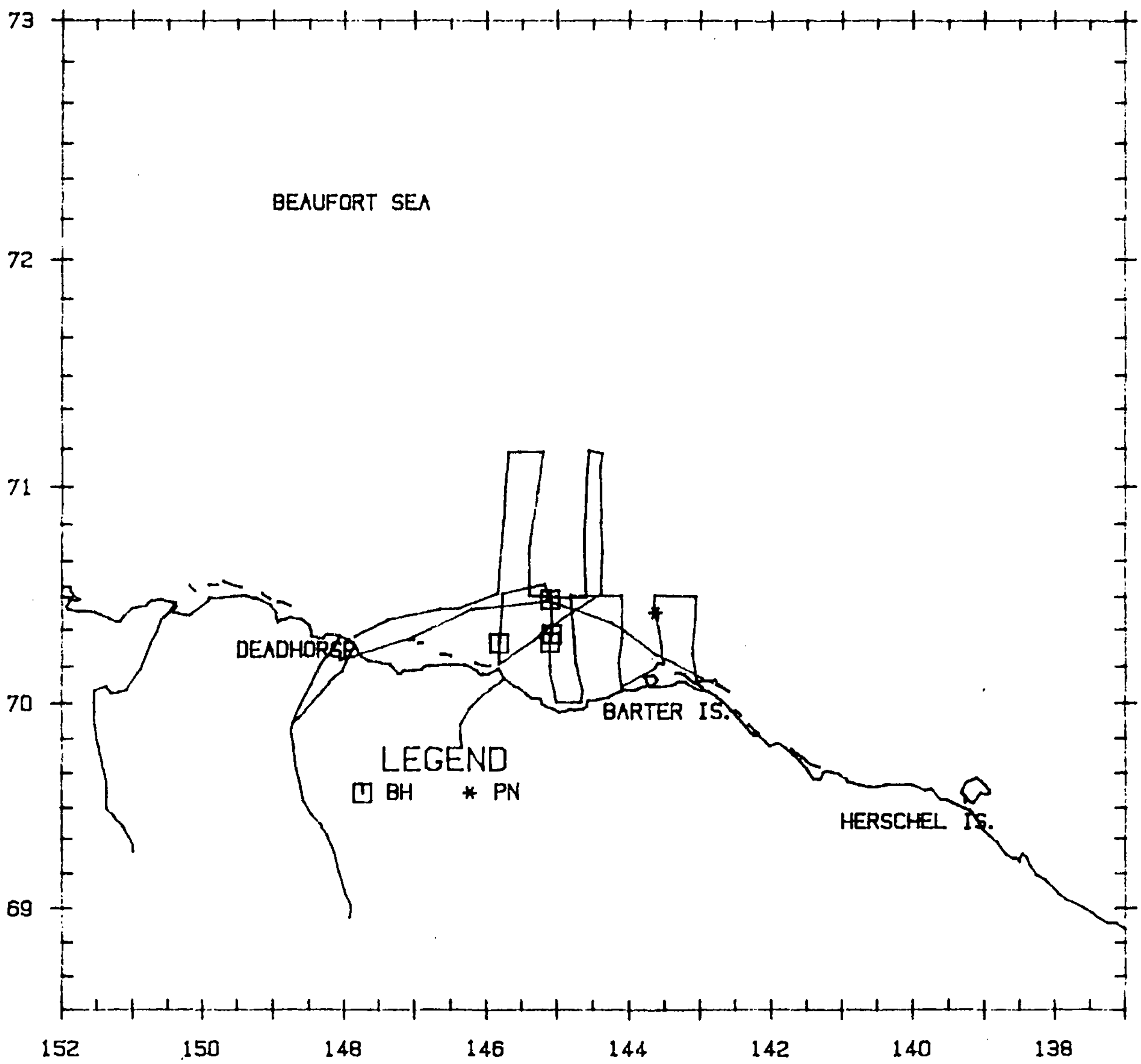
T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
3/0	70°20.7'	146°26.5'	-	BO	SW	90	0	B2	27



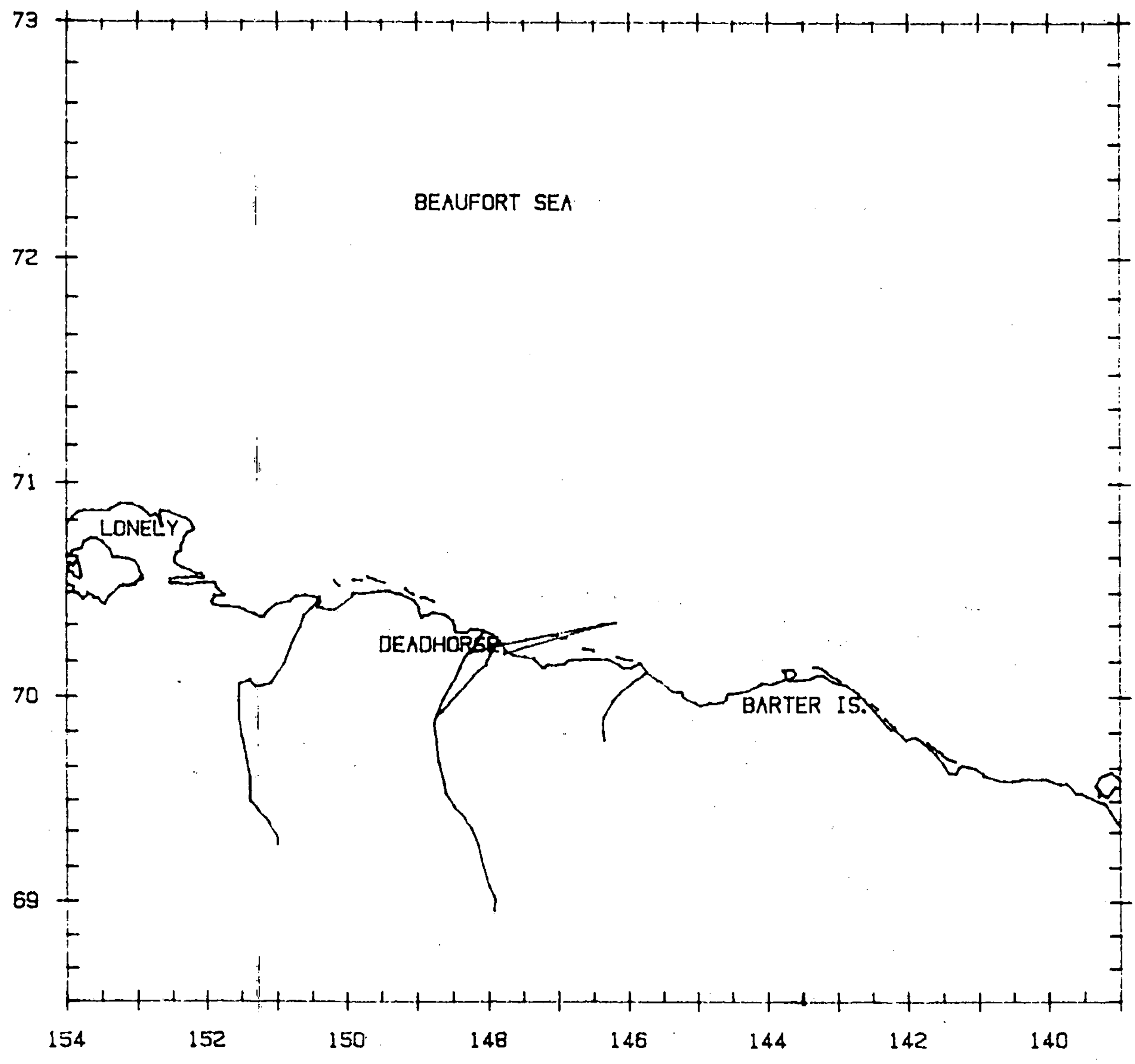
TWIN OTTER FLIGHT 13: 17 September 1987

Bowhead Whales

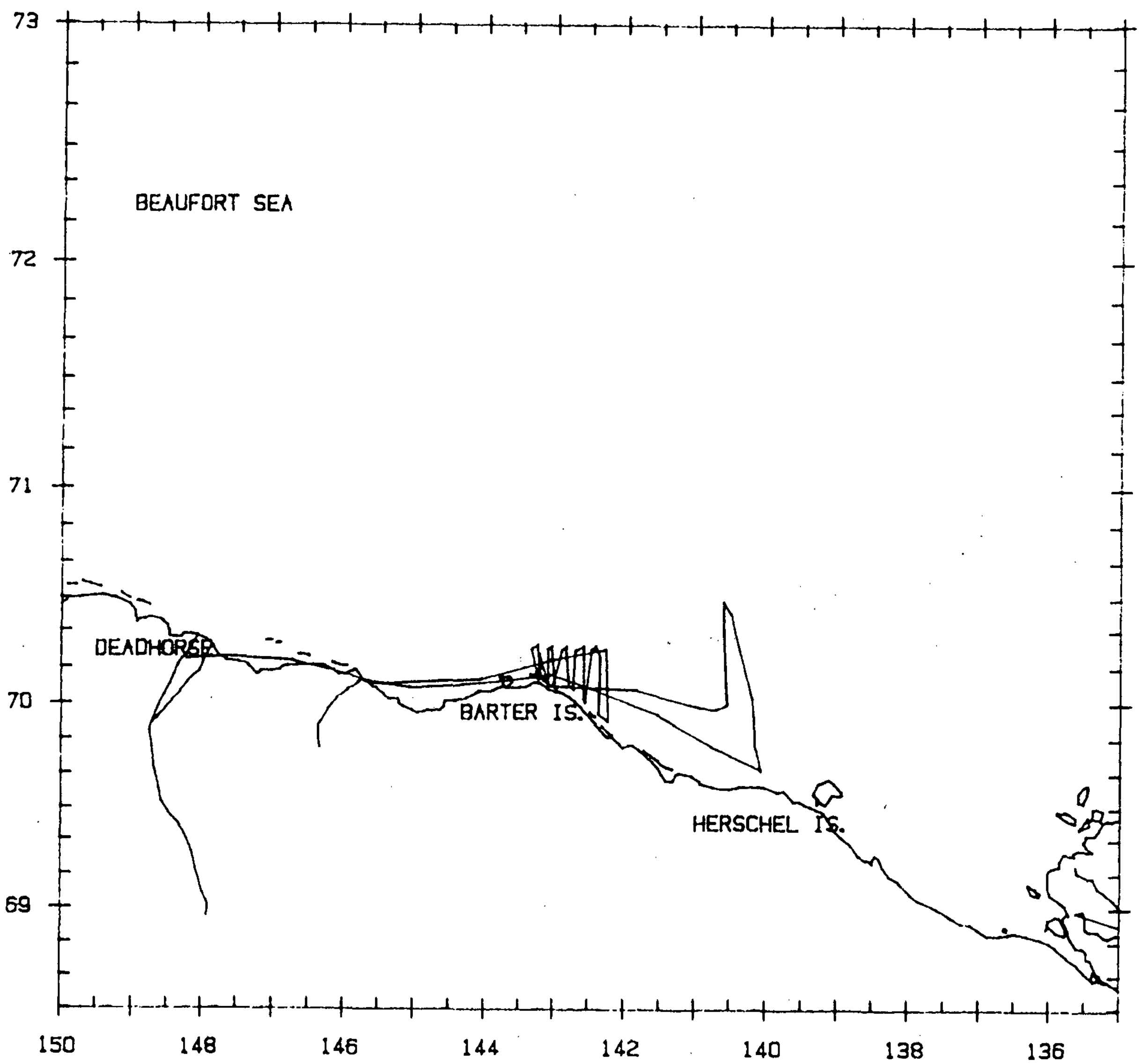
T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	70°16.8'	145°06.5'	513	BO	SW	270	0	B4	29
1/0	70°18.9'	145°04.9'	1423	BO	SW	270	0	B3	29
1/0	70°28.2'	145°06.1'	582	BO	SW	90	0	B3	37
1/0	70°16.6'	145°50.0'	743	BO	SW	360	1	B4	22



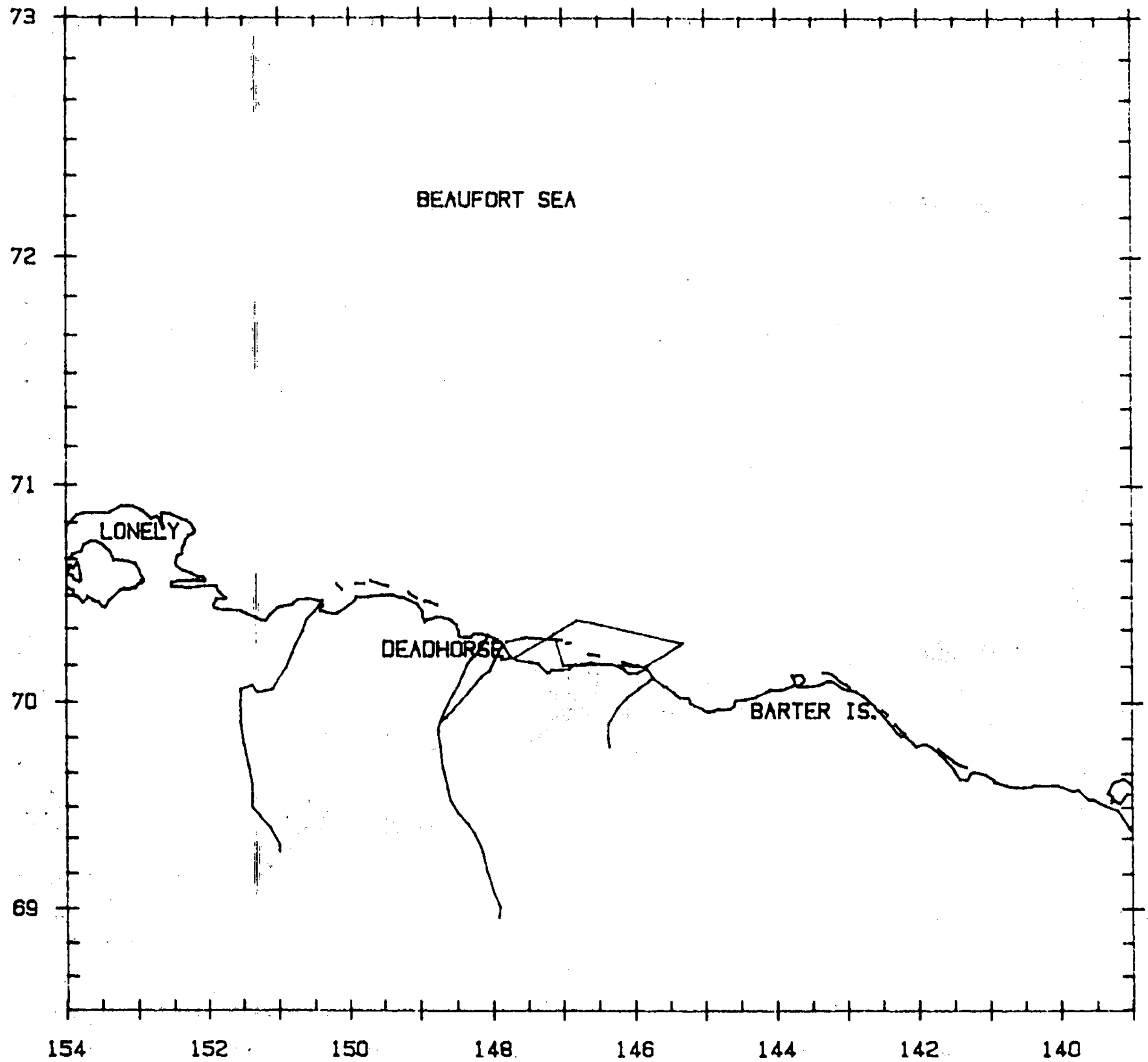
TWIN OTTER FLIGHT 14: 18 September 1987



TWIN OTTER FLIGHT 15: 20 September 1987



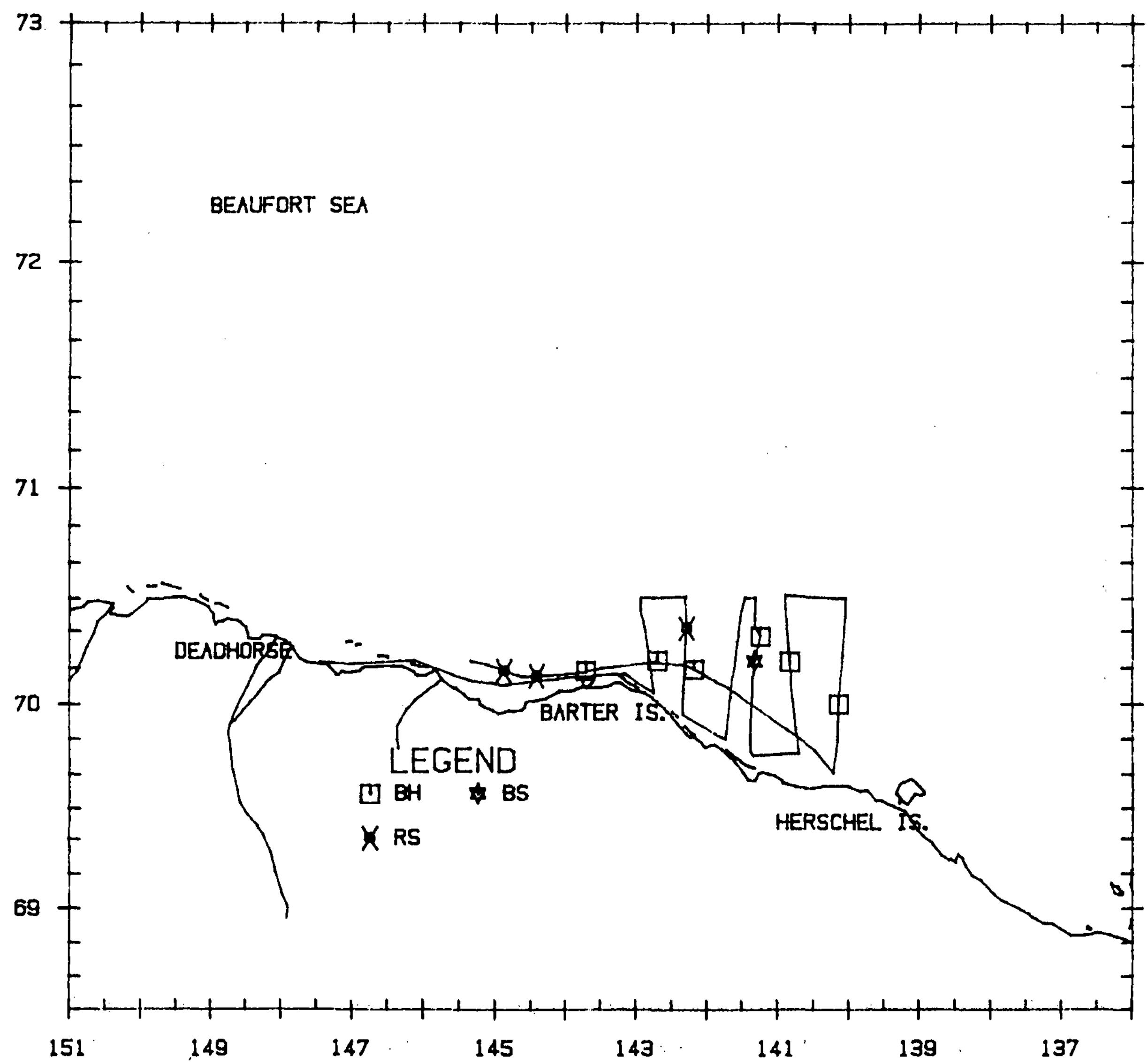
TWIN OTTER FLIGHT 16: 21 September 1987



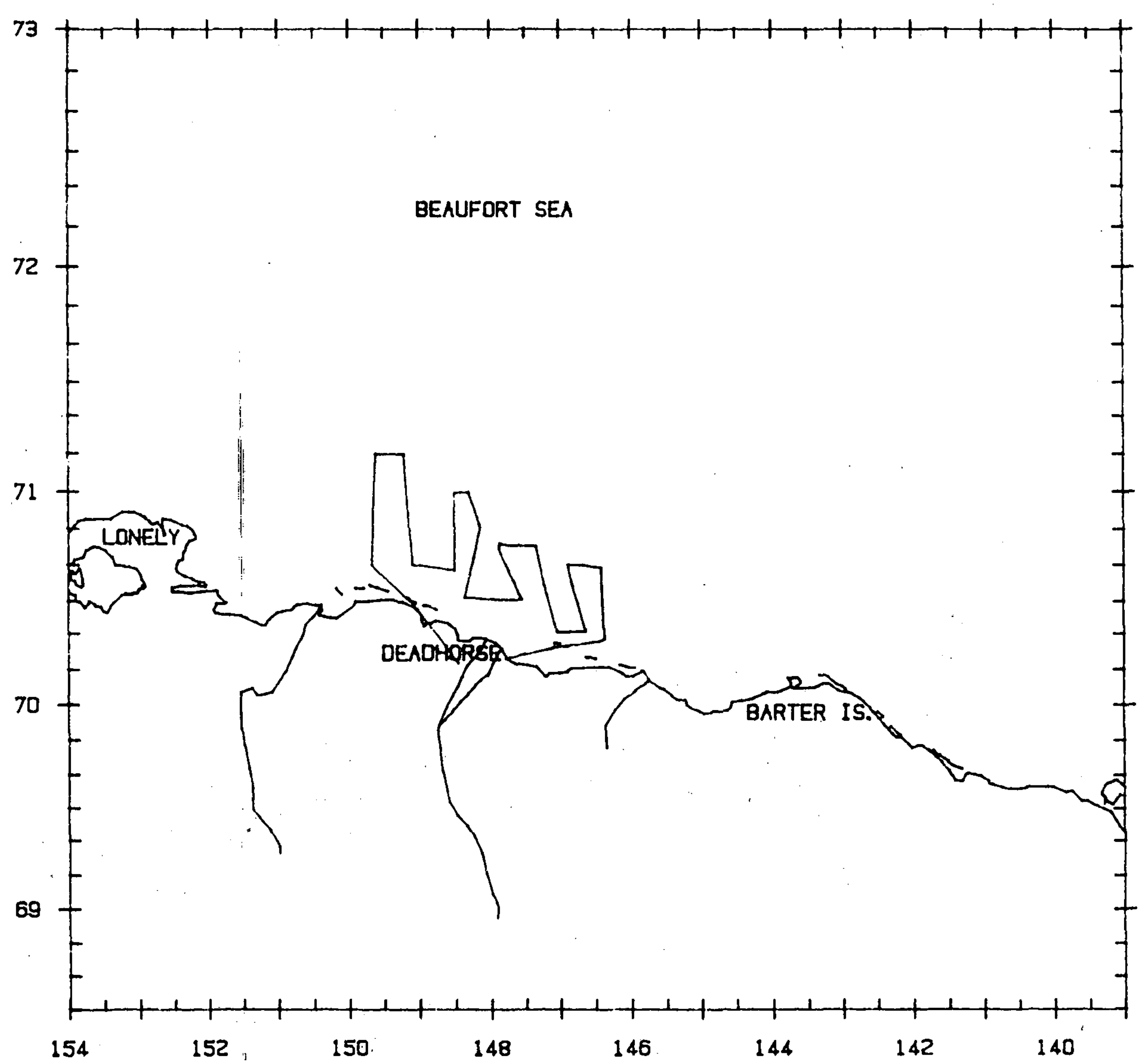
TWIN OTTER FLIGHT 17: 22 September 1987

Bowhead Whales

T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	70°09.2'	143°42.9'	-	BO	SW	270	0	B3	9
1/0	70°12.1'	142°42.6'	-	SP	SW	270	0	B2	22
1/0	70°09.7'	142°11.3'	-	BO	SW	260	0	B3	26
1/0	70°00.1'	140°08.7'	503	BO	DI	-	0	B4	59
1/0	70°11.7'	140°50.3'	983	BO	SW	300	0	B3	48
1/0	70°18.7'	141°15.0'	230	BO	SW	250	0	B2	53



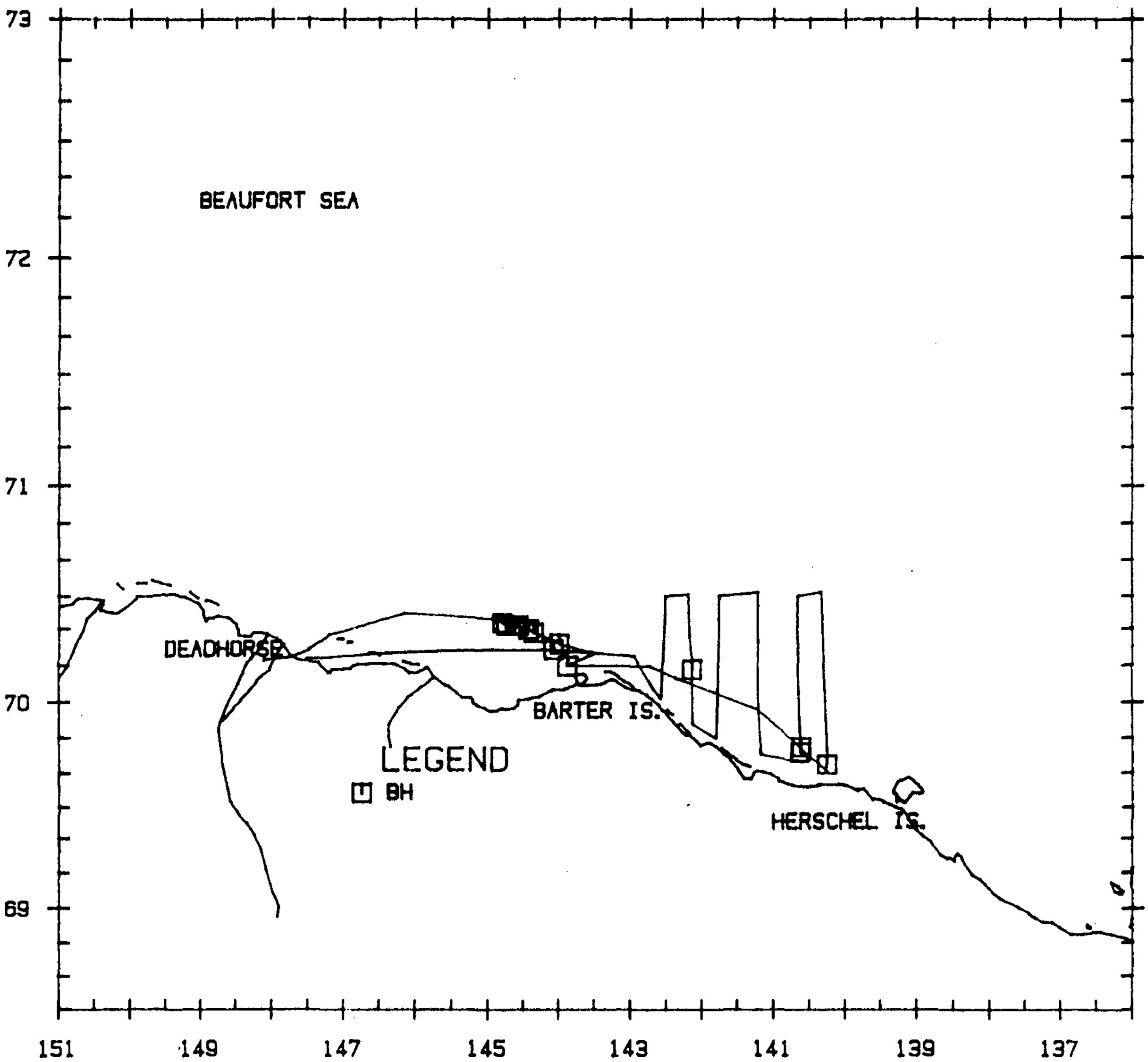
TWIN OTTER FLIGHT 18: 26 September 1987



TWIN OTTER FLIGHT 19: 27 September 1987

Bowhead Whales

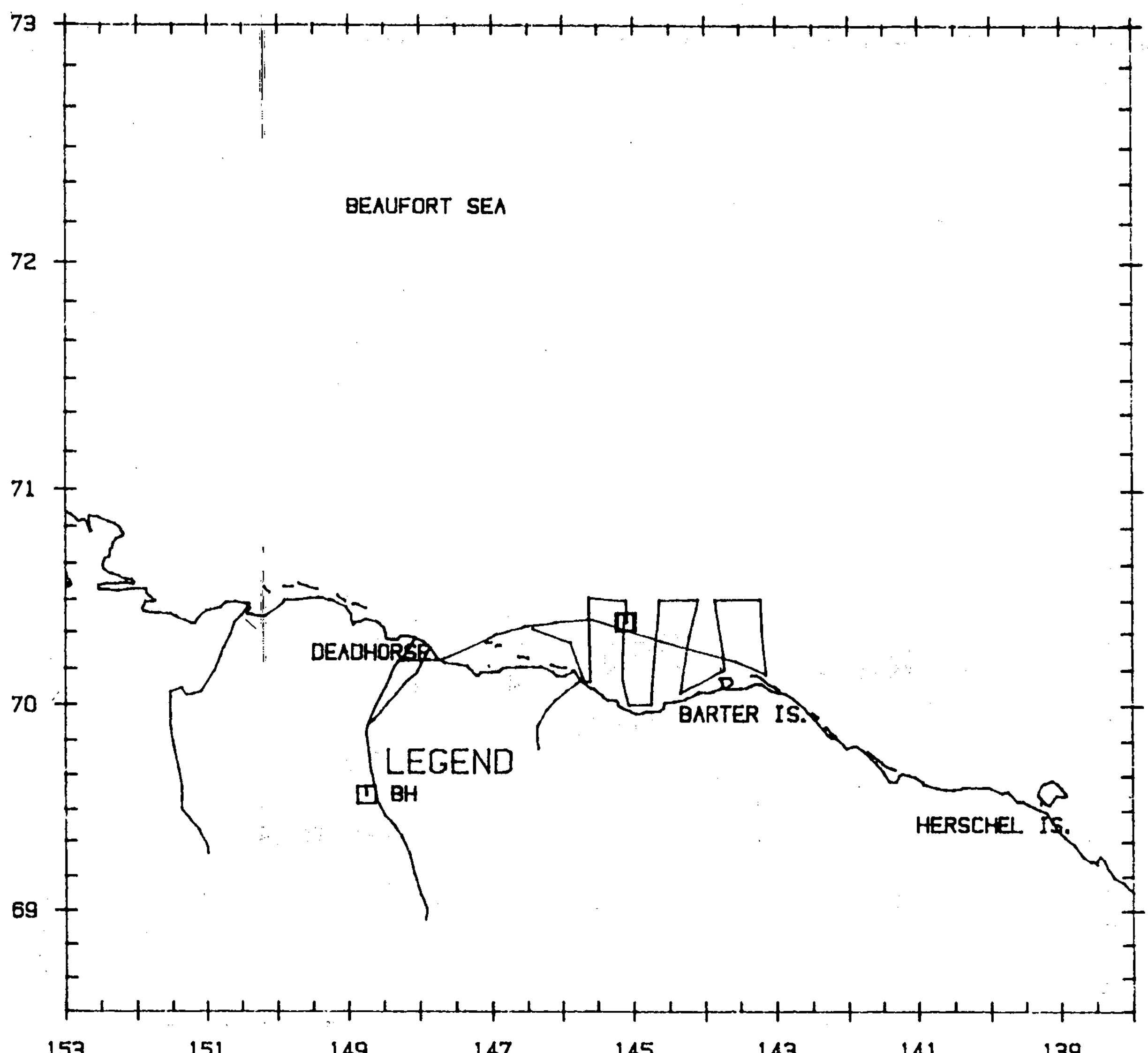
T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	70°21.7'	144°48.4'	-	BO	SW	360	0	B2	37
1/0	70°21.0'	144°45.2'	-	BO	SW	45	0	B2	37
1/0	70°21.0'	144°35.0'	-	BO	SW	45	0	B2	42
1/0	70°21.0'	144°38.0'	-	BO	SW	180	0	B2	42
1/0	70°19.9'	144°26.3'	1384	BO	SW	245	0	B2	33
1/0	70°19.0'	144°22.0'	-	BO	SW	240	0	B2	33
1/0	70°16.0'	144°00.0'	-	BO	SW	240	0	B2	37
1/0	70°10.0'	143°53.0'	-	SP	SW	180	0	B2	15
1/0	69°42.5'	140°16.0'	531	BO	SW	260	0	B2	27
2/0	69°47.5'	140°37.6'	3312	SP	SW	250	0	B2	27
1/0	69°46.0'	140°38.5'	-	BO	RE	-	0	B2	27
1/0	70°09.0'	142°09.0'	1126	BW	SW	240	0	B2	26
1/0	70°14.5'	144°05.3'	601	BW	RE	240	0	B2	18



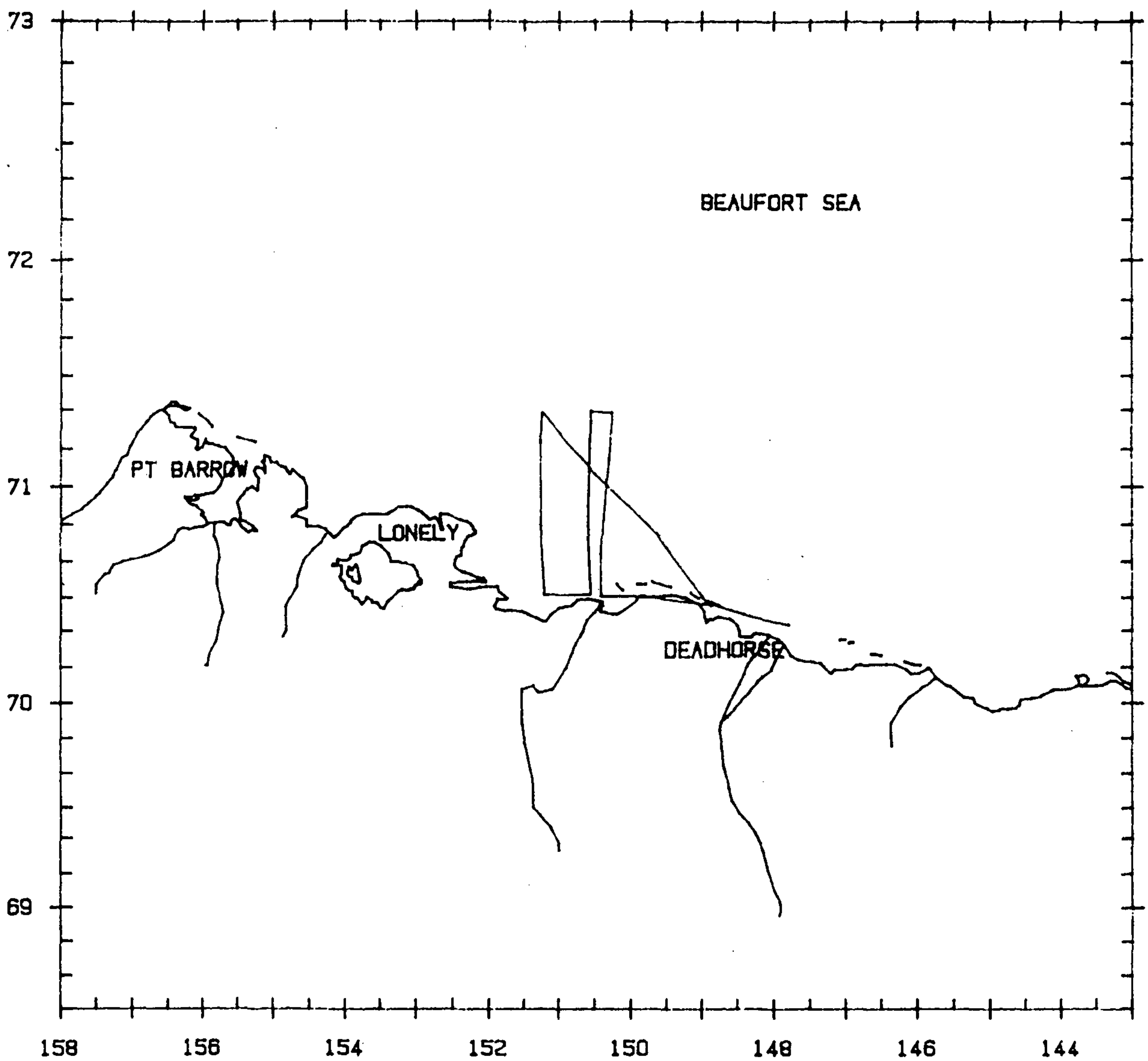
TWIN OTTER FLIGHT 20: 28 September 1987

Bowhead Whales

T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	70°22.8'	145°07.8'	1032	BW	SW	300	0	B6	33
1/0	70°23.0'	145°06.0'	113	BW	SW	90	0	B6	33



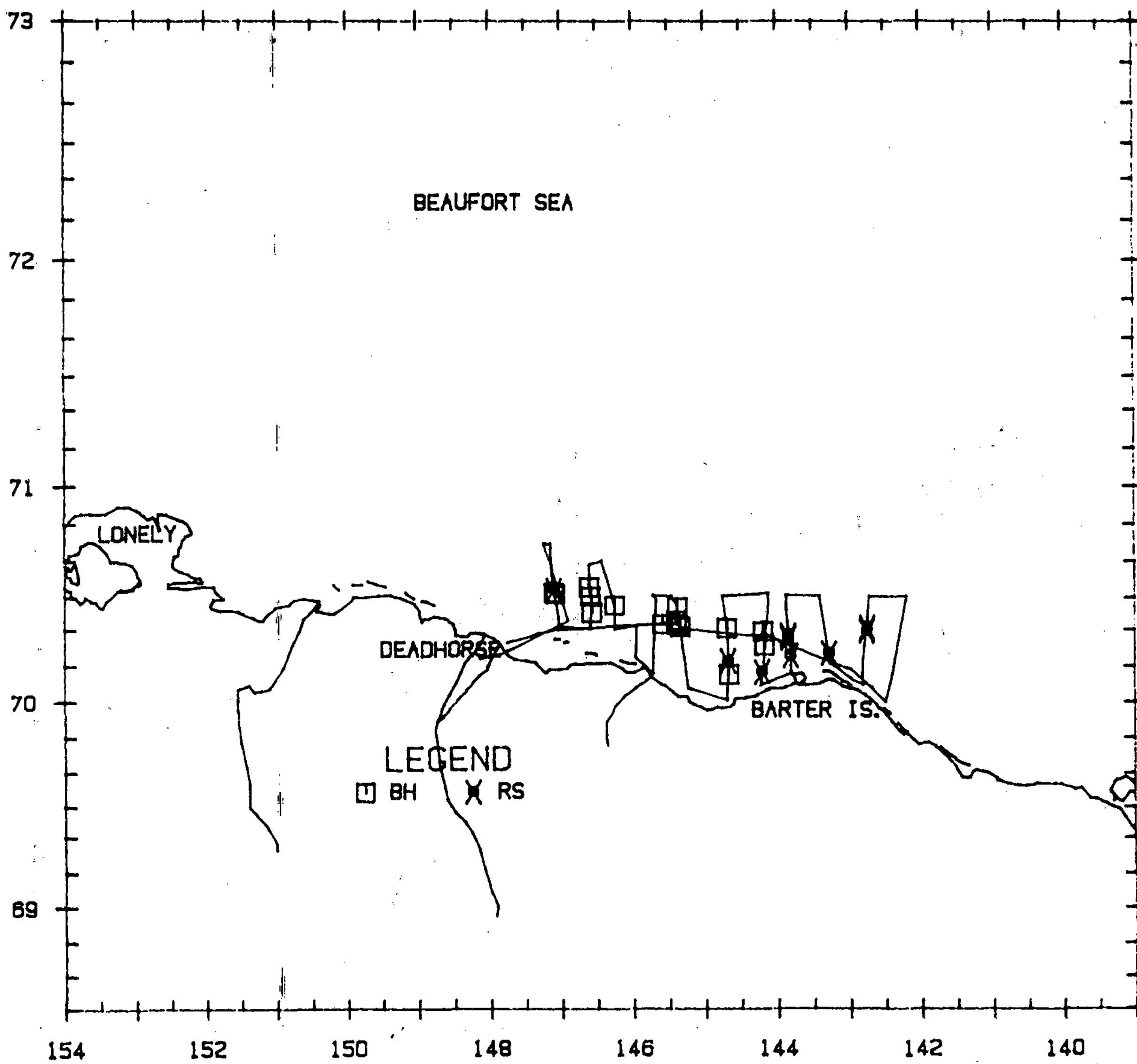
TWIN OTTER FLIGHT 21: 28 September 1987



TWIN OTTER FLIGHT 22: 29 September 1987

Bowhead Whales

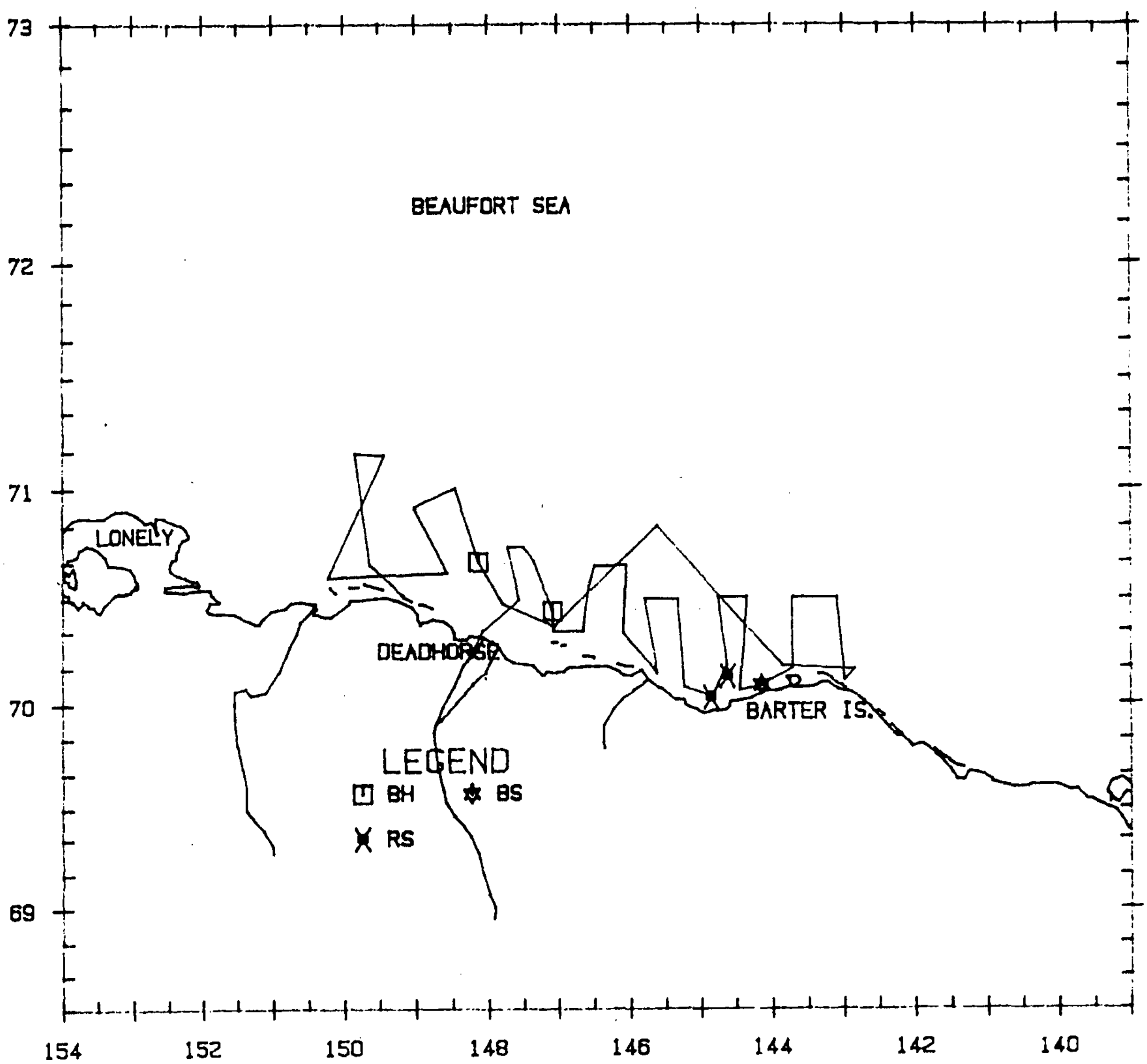
T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	70°29.4'	147°04.9'	921	BO	DI	230	0	B1	18
1/0	70°29.9'	147°06.3'	1637	BO	SW	240	0	B1	18
1/0	70°24.5'	146°33.9'	1090	BW	SW	240	0	B1	27
1/0	70°28.9'	146°35.0'	954	BO	SW	270	0	B1	27
1/0	70°33.0'	146°36.3'	621	SP	SW	240	0	B1	35
1/0	70°26.3'	146°14.9'	-	BW	SW	255	0	B1	31
1/0	70°25.9'	145°22.8'	2533	BW	SW	240	0	B1	37
1/0	70°07.5'	144°39.8'	-	BW	RE	-	0	B1	15
1/0	70°20.2'	144°41.6'	3573	BW	NA	240	0	B1	37
1/0	70°15.3'	144°10.5'	1074	BO	SW	230	0	B1	37
1/0	70°19.3'	144°11.8'	1217	BO	SW	250	0	B1	37
2/1	70°20.6'	145°20.8'	1202	BO	RE	240	0	B1	26
1/0	70°22.3'	145°23.8'	-	BW	RE	350	0	B1	26
1/0	70°21.4'	145°35.4'	1467	BO	SW	240	0	B1	26



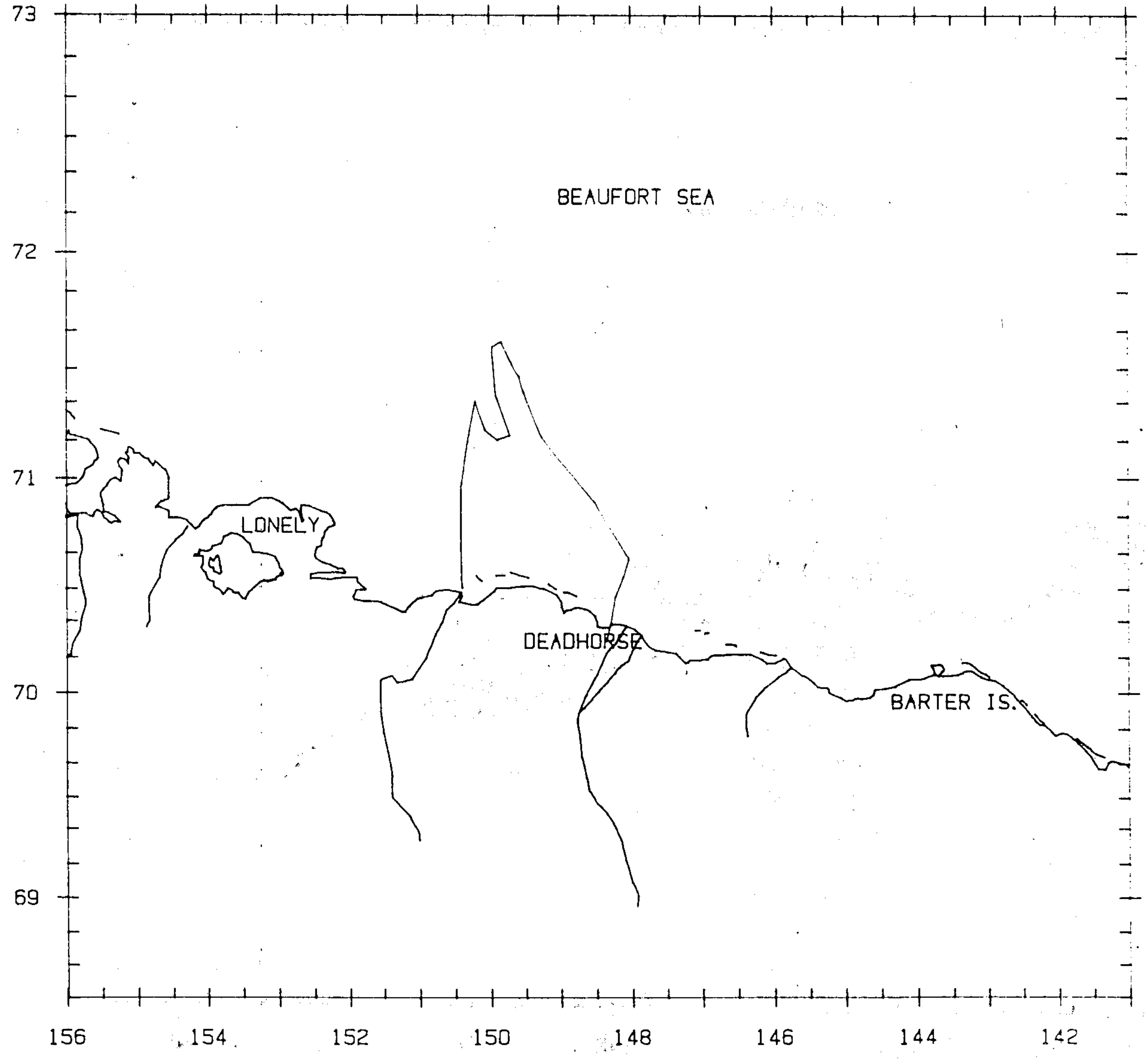
TWIN OTTER FLIGHT 23: 30 September 1987

Bowhead Whales

T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
2/0	70°25.7'	147°04.3'	226	BW	RE	-	0	B1	18
1/0	70°40.6'	148°08.4'	1412	BW	SW	240	0	B2	24



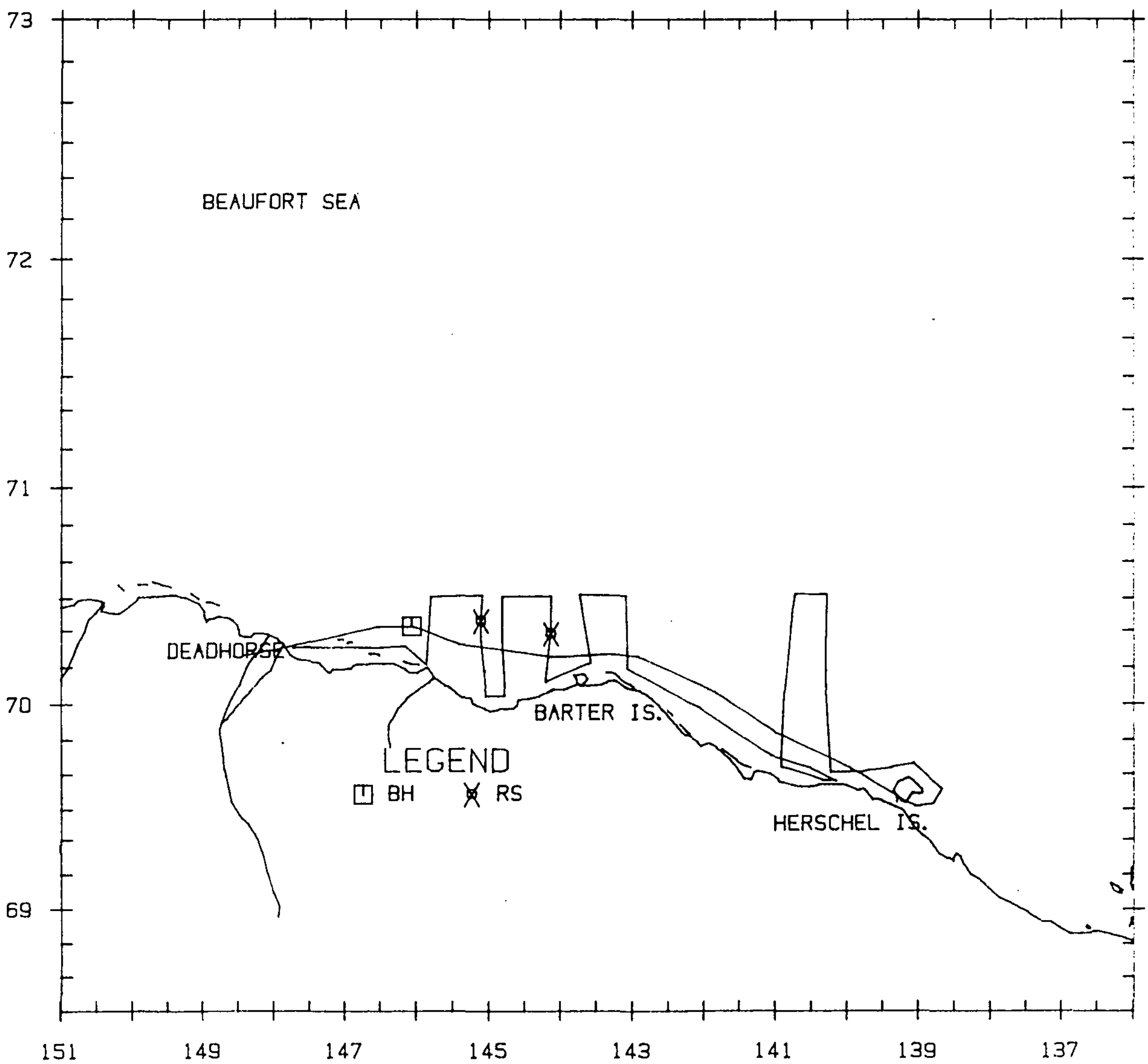
TWIN OTTER FLIGHT 24: 1 October 1987



TWIN OTTER FLIGHT 25: 5 October 1987

Bowhead Whales

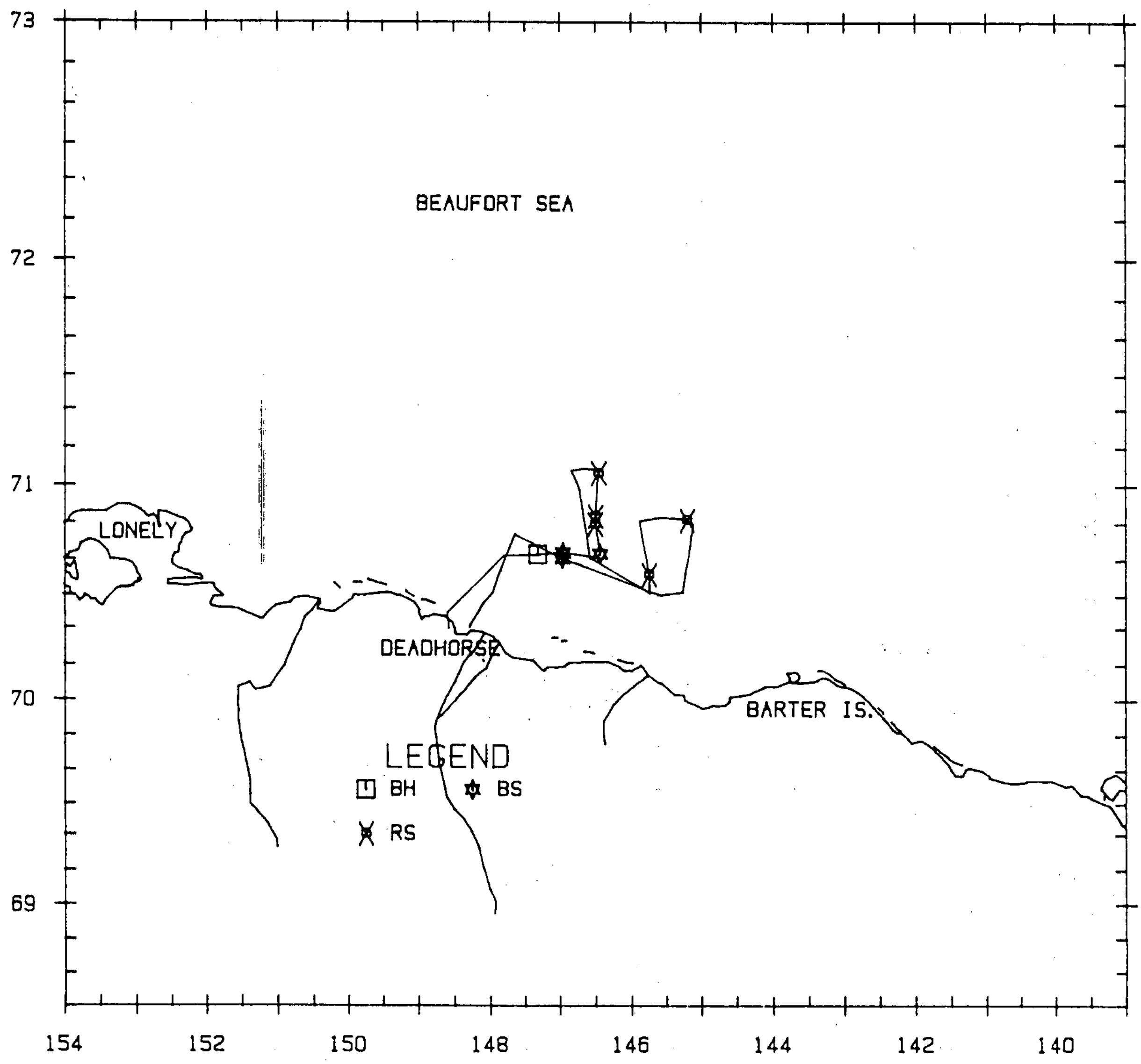
T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	70°20.8'	146°02.8'	-	BW	SW	240	0	B1	27



TWIN OTTER FLIGHT 26: 5 October 1987

Bowhead Whales

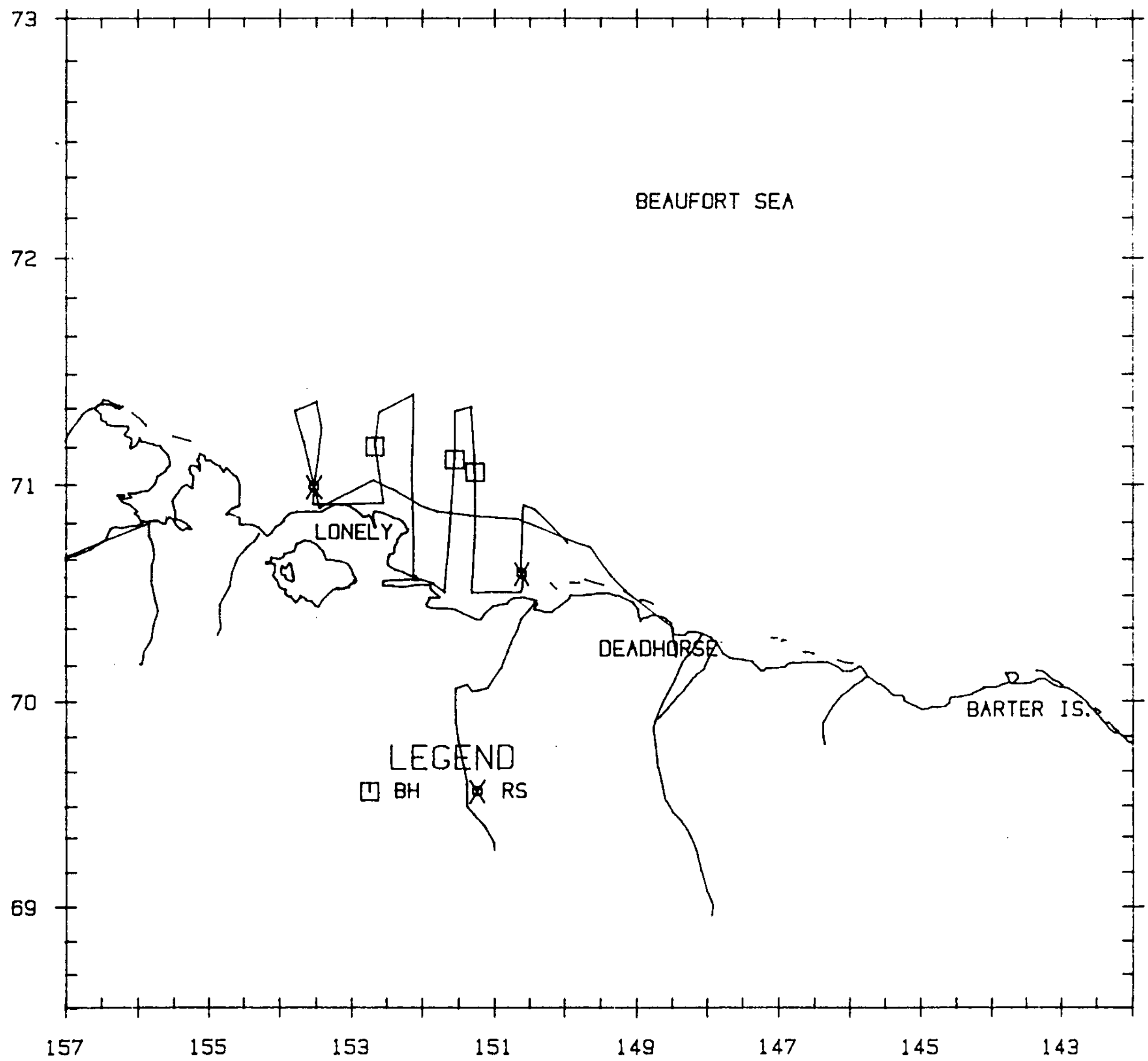
T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	70°41.2'	147°17.7'	-	BW	SW	270	0	B1	40



TWIN OTTER FLIGHT 27: 6 October 1987

Bowhead Whales

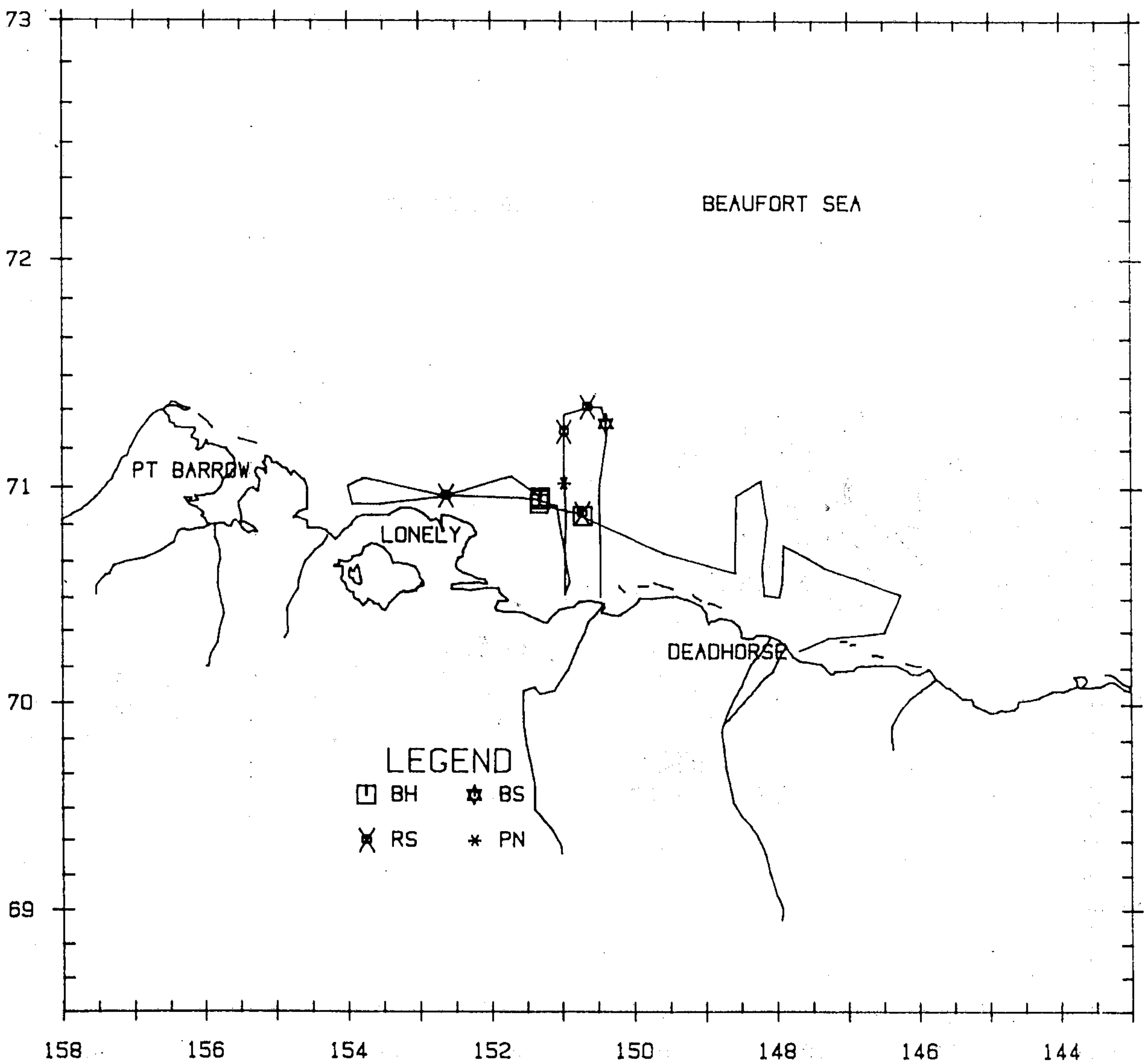
T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
5/0	71°09.9'	152°39.3'	341	BO	SW	260	0	B1	9
1/0	71°06.5'	151°32.4'	216	BO	SW	260	0	B1	11
2/0	71°03.1'	151°15.5'	494	BO	SW	240	0	B1	20



TWIN OTTER FLIGHT 28: 7 October 1987

Bowhead Whales

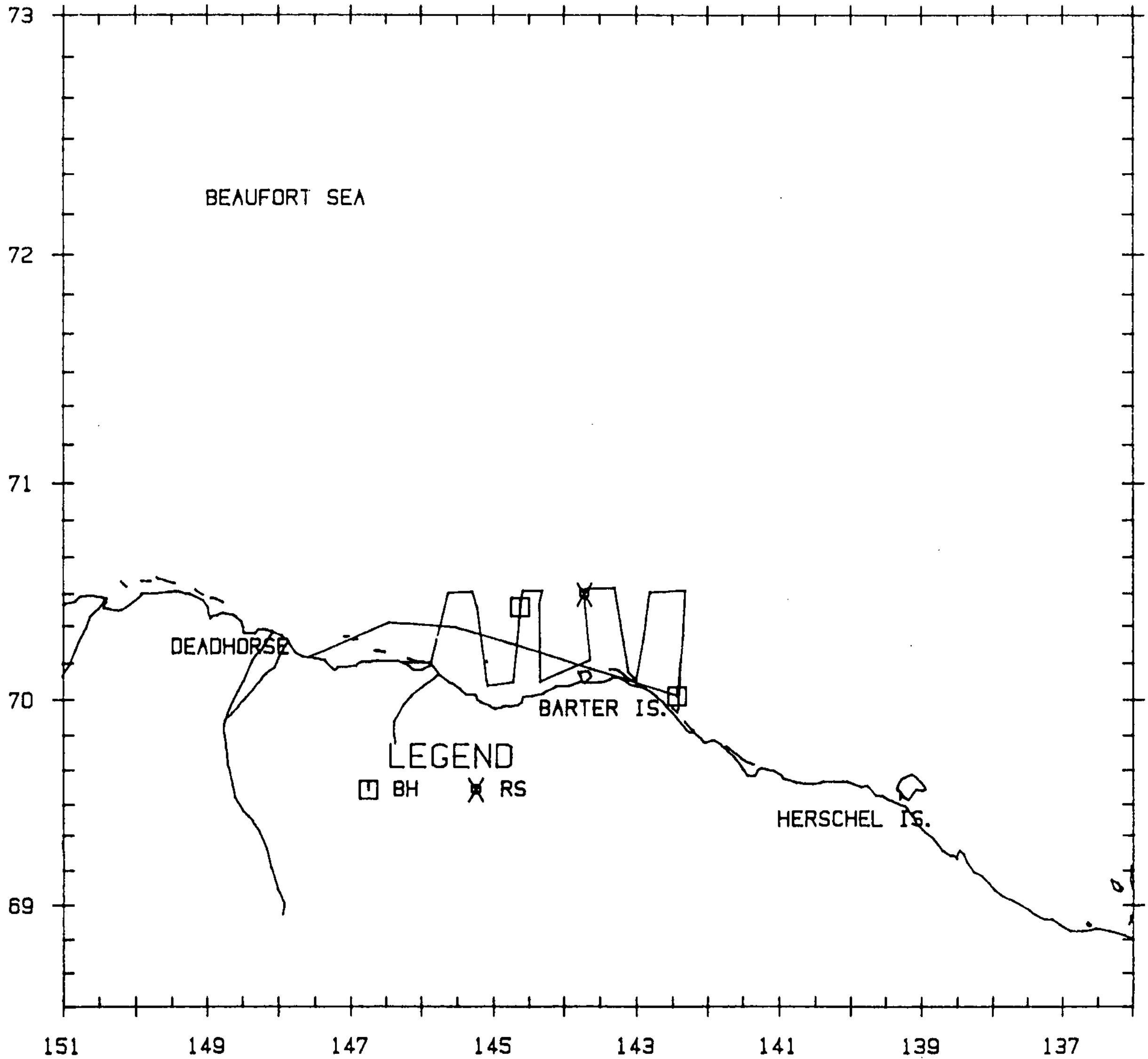
T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	70°52.5'	150°41.3'	-	BO	DI	-	0	B1	11
6/0	70°55.8'	151°18.2'	-	BO	FE	-	0	B1	15
8/0	70°56.9'	151°16.7'	-	BO	FE	-	0	B1	15
5/0	70°57.6'	151°17.0'	-	BO	FE	-	0	B1	15



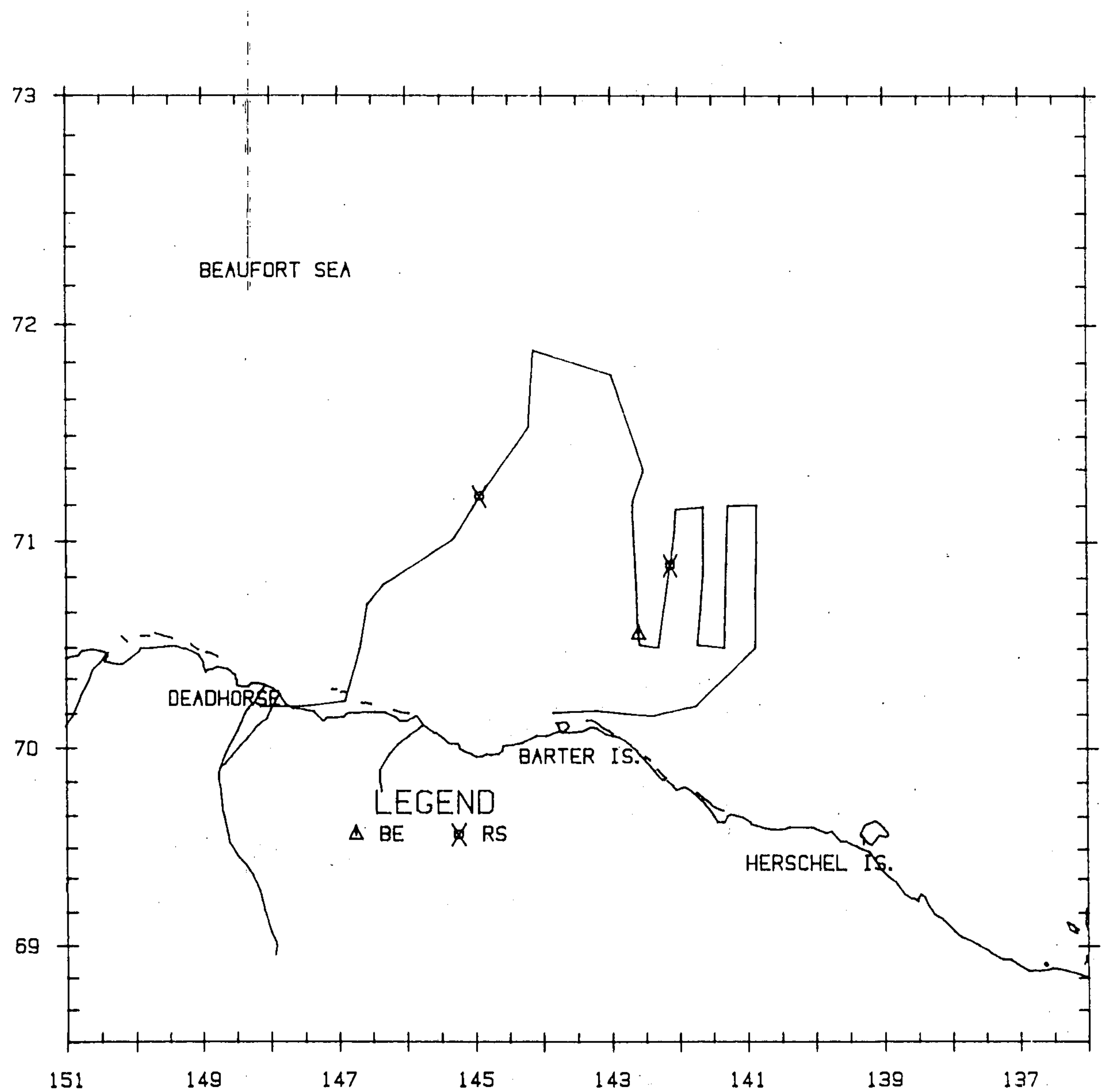
TWIN OTTER FLIGHT 29: 8 October 1987

Bowhead Whales

T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	70°00.9'	142°25.0'	-	SP	SW	90	0	B1	18
2/0	70°25.0'	144°36.9'	1448	BO	SW	240	0	B2	48



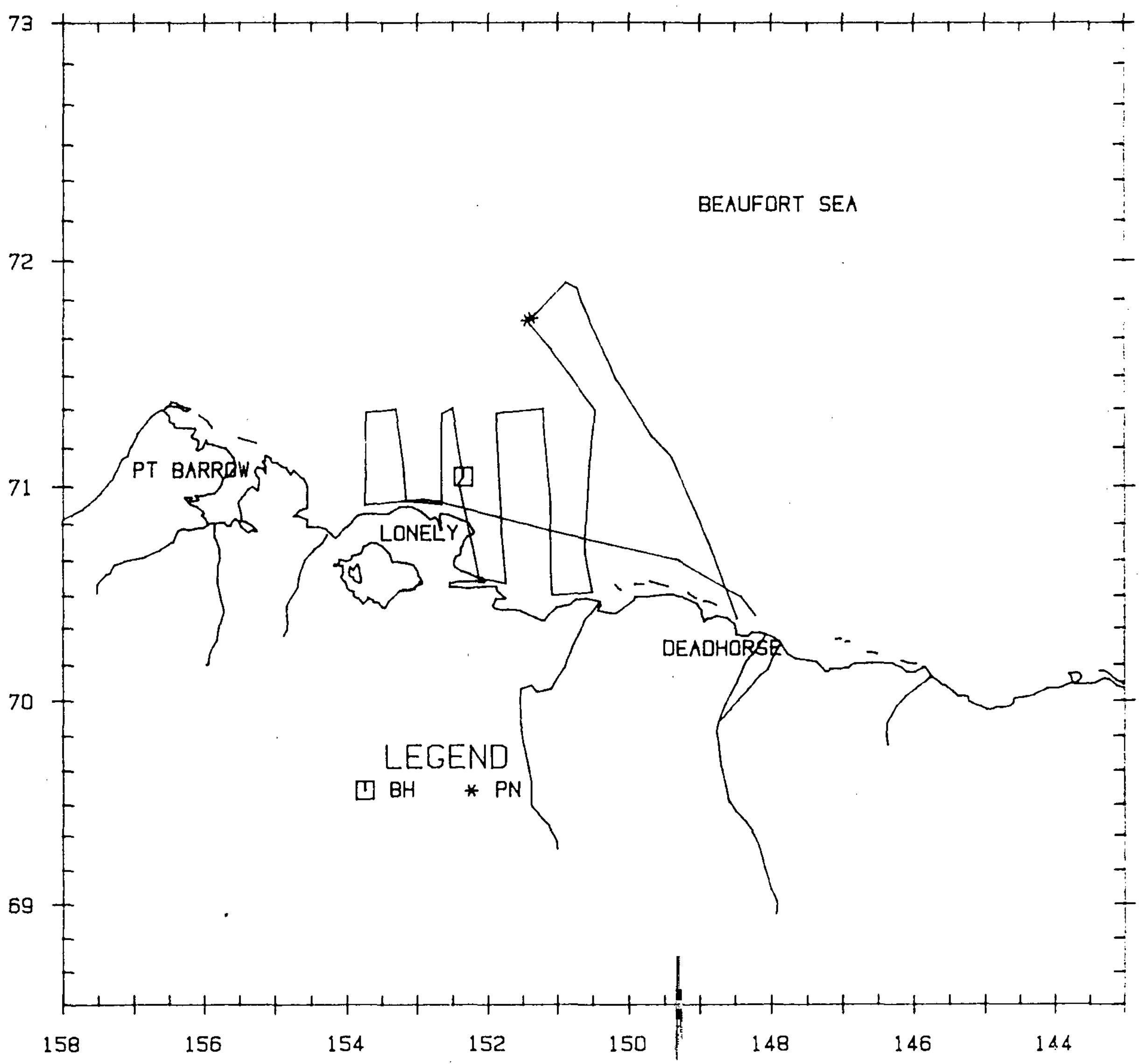
TWIN OTTER FLIGHT 30: 9 October 1987



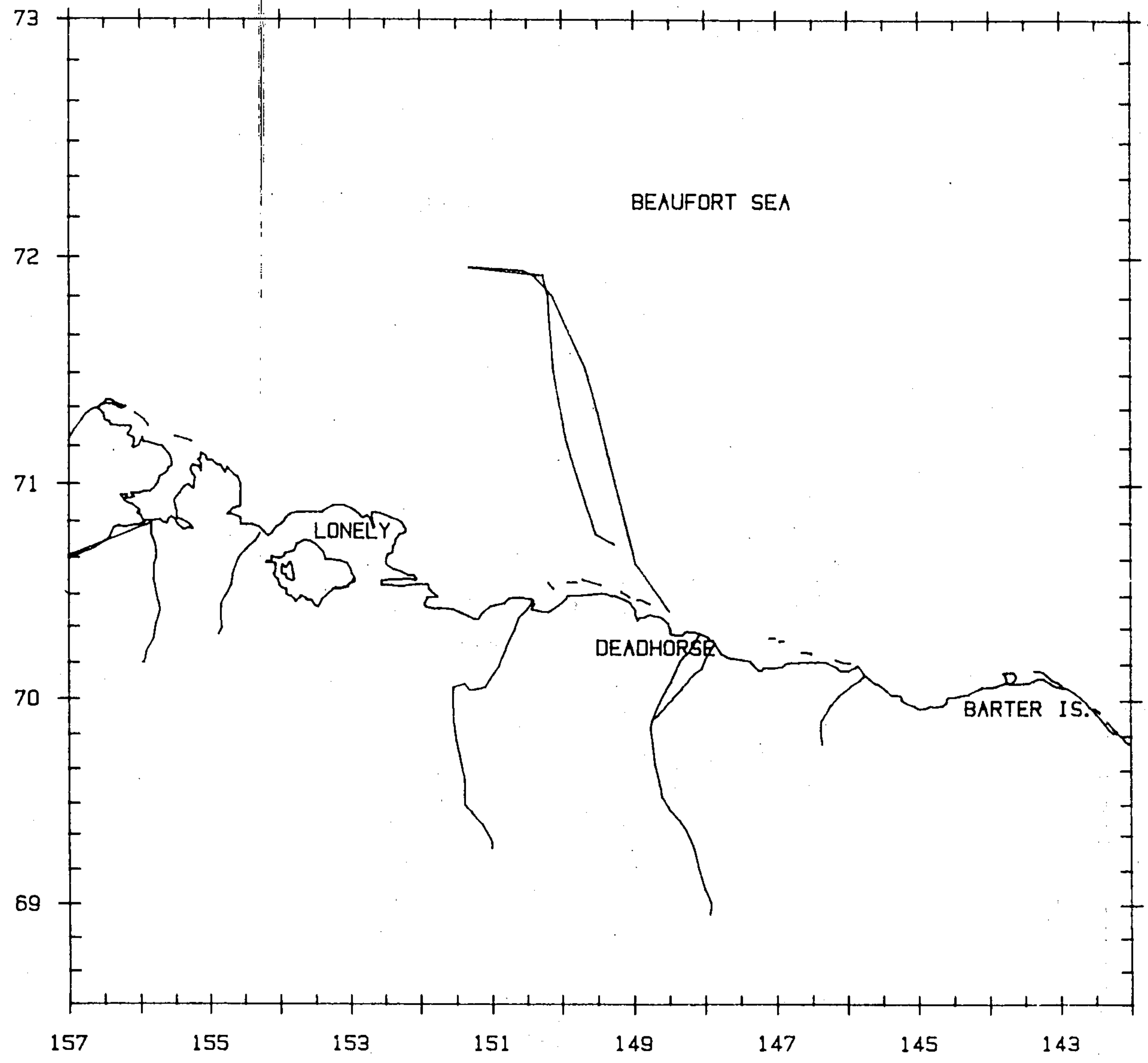
TWIN OTTER FLIGHT 31: 10 October 1987

Bowhead Whales

T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
2/0	71°02.6'	152°20.4'	915	BO	SW	240	0	B1	9



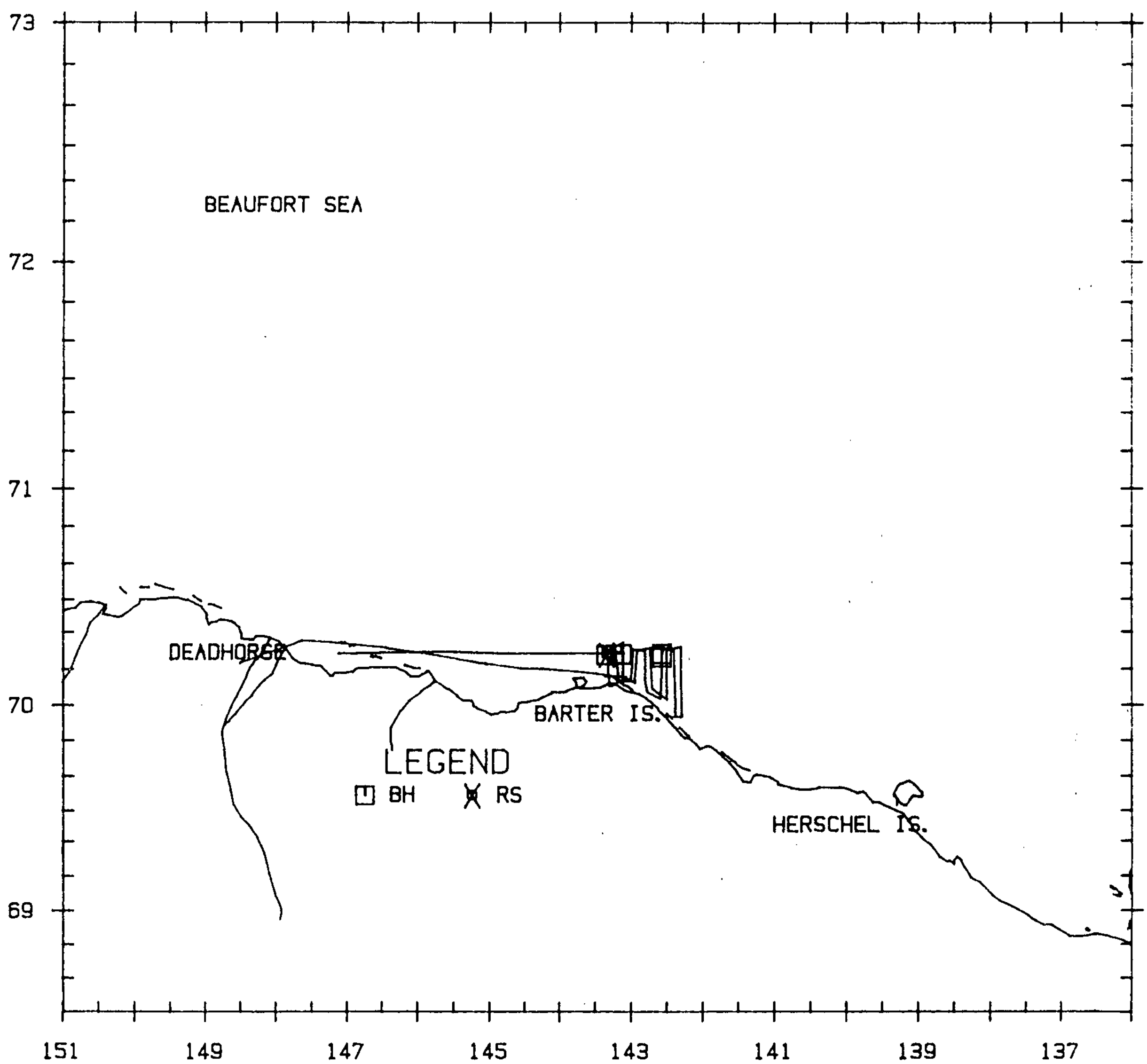
TWIN OTTER FLIGHT 32: 11 October 1987



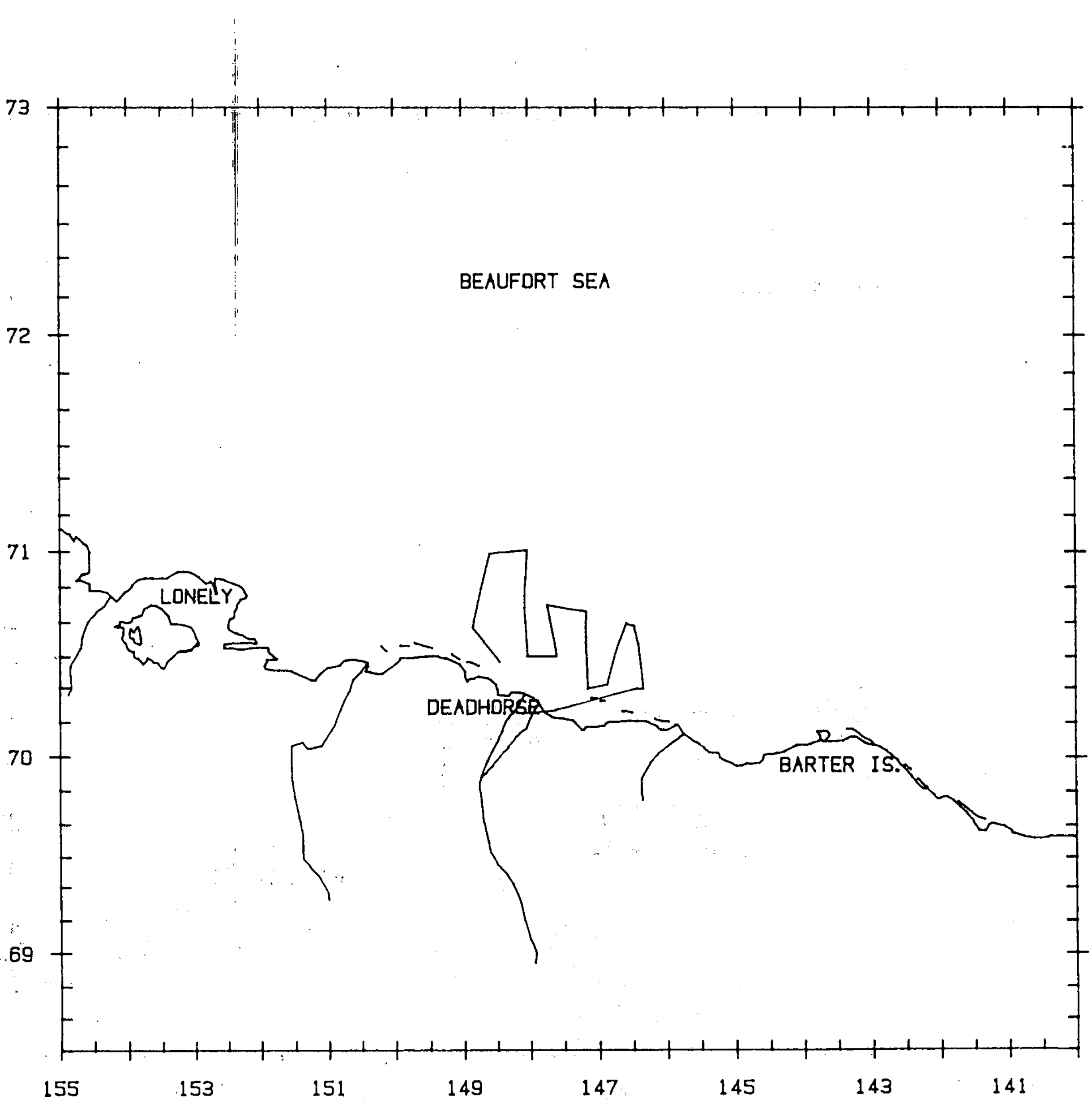
TWIN OTTER FLIGHT 33: 13 October 1987

Bowhead Whales

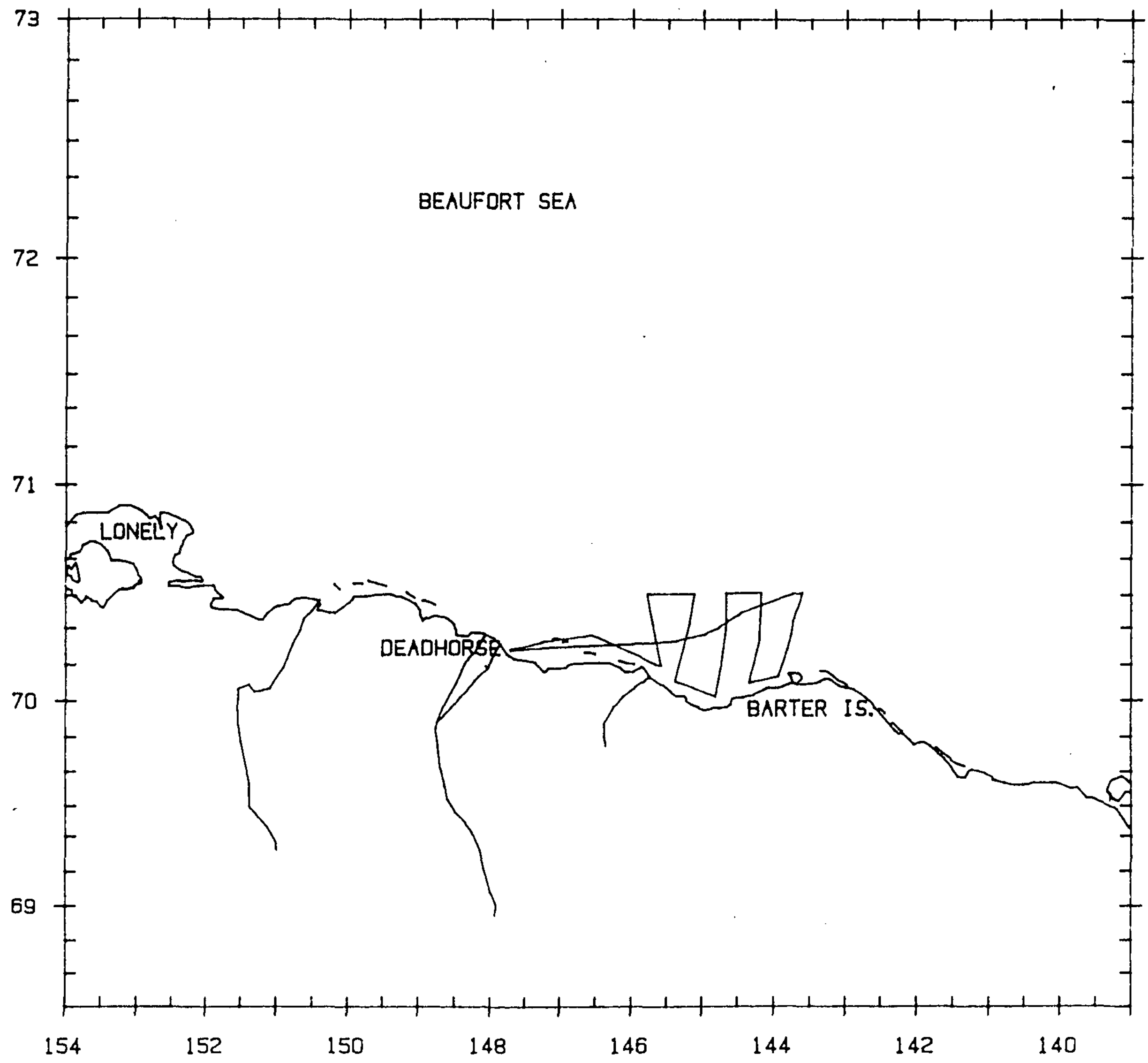
T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	70°14.0'	143°20.0'	478	BO	SW	240	0	B2	13
1/0	70°14.4'	142°33.5'	471	BO	SW	240	0	B4	29
1/0	70°13.4'	142°33.5'	42	BO	SW	240	0	B4	29
3/0	70°14.2'	143°07.1'	-	BO	SW	245	0	B2	18



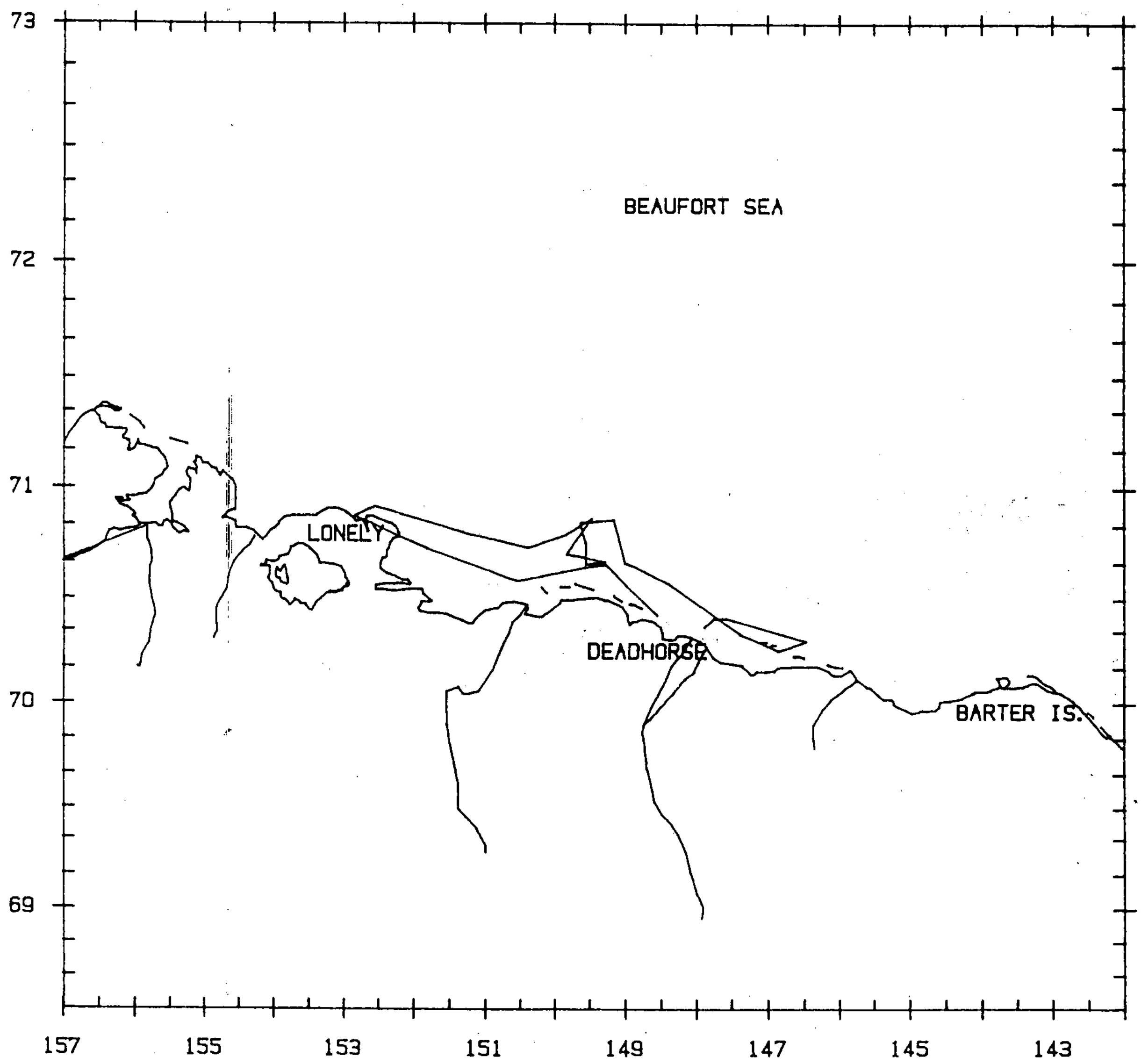
TWIN OTTER FLIGHT 34: 14 October 1987



TWIN OTTER FLIGHT 35: 14 October 1987



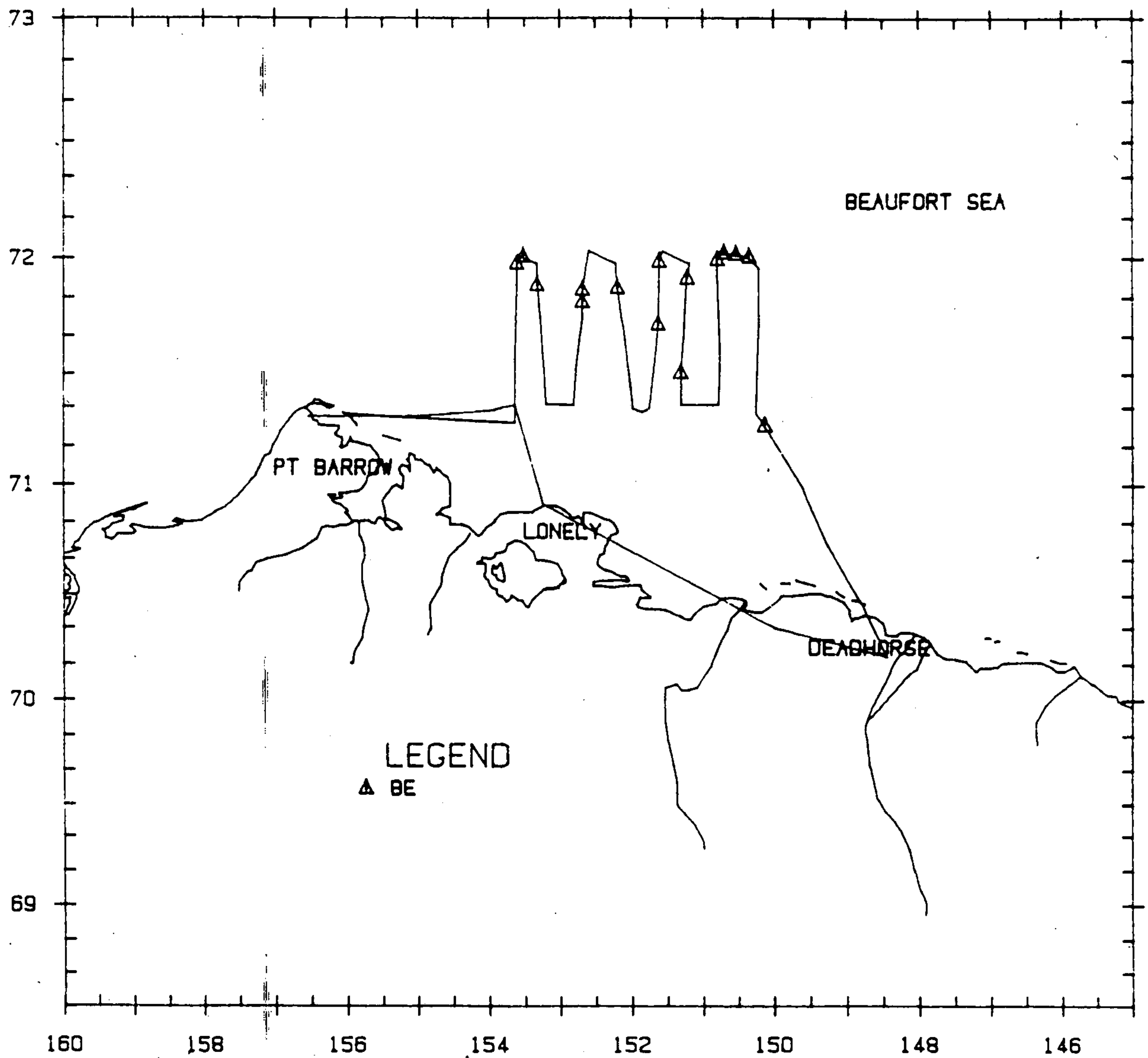
TWIN OTTER FLIGHT 36: 15 October 1987



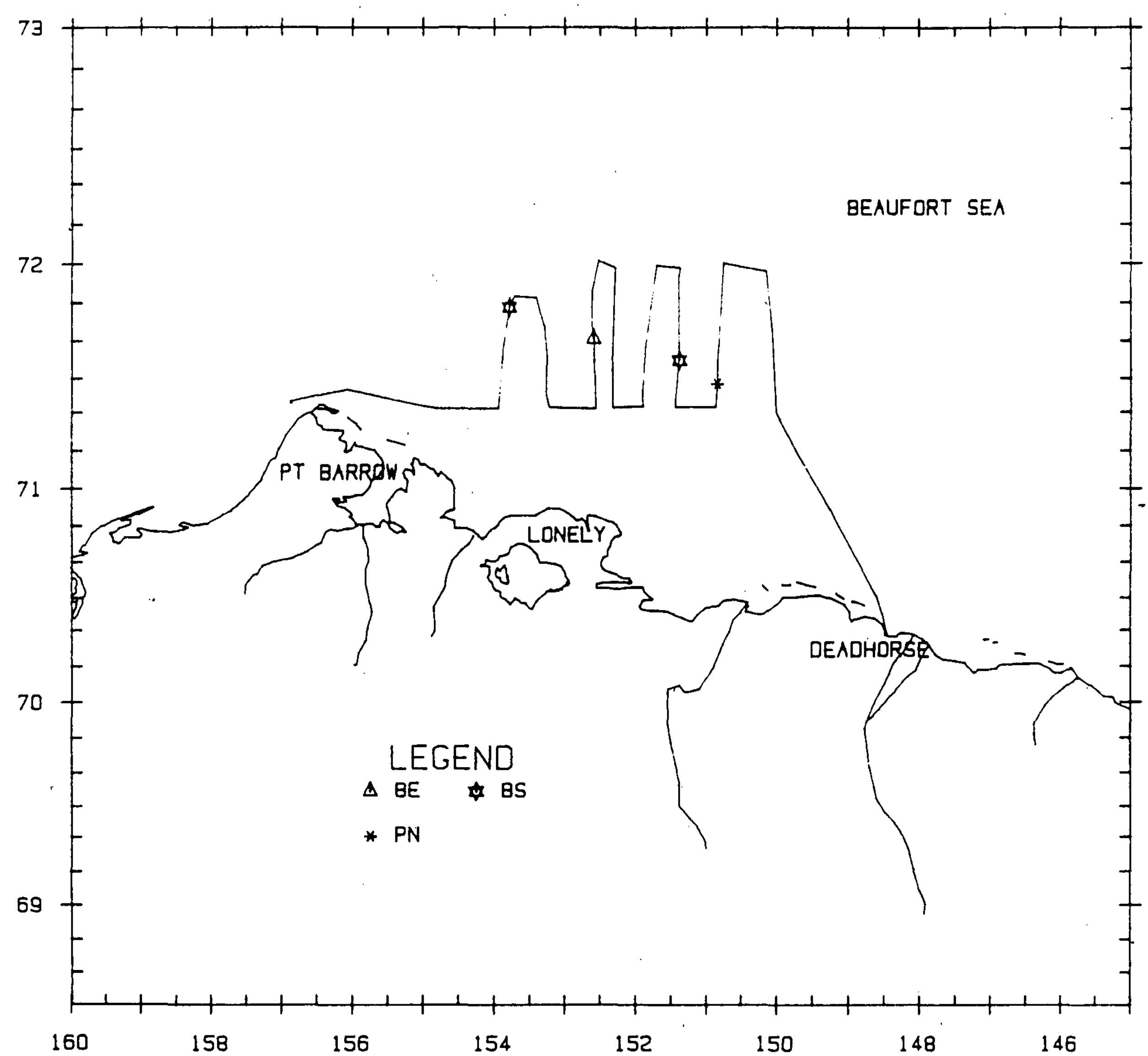
DAILY FLIGHT SUMMARIES - GRUMMAN GOOSE

This appendix consists of Flight Tracks 5, 15, 21, 24, 25, 33, and 35 through 41, depicting aerial surveys flown over portions of the study area between 1 September and 31 October 1987, by NOSC/SEACO, Inc., aboard a Grumman Goose aircraft. An explanation of how the maps were generated and the symbols used appears at the beginning of Appendix B.

GRUMMAN GOOSE FLIGHT 5: 6 September 1987

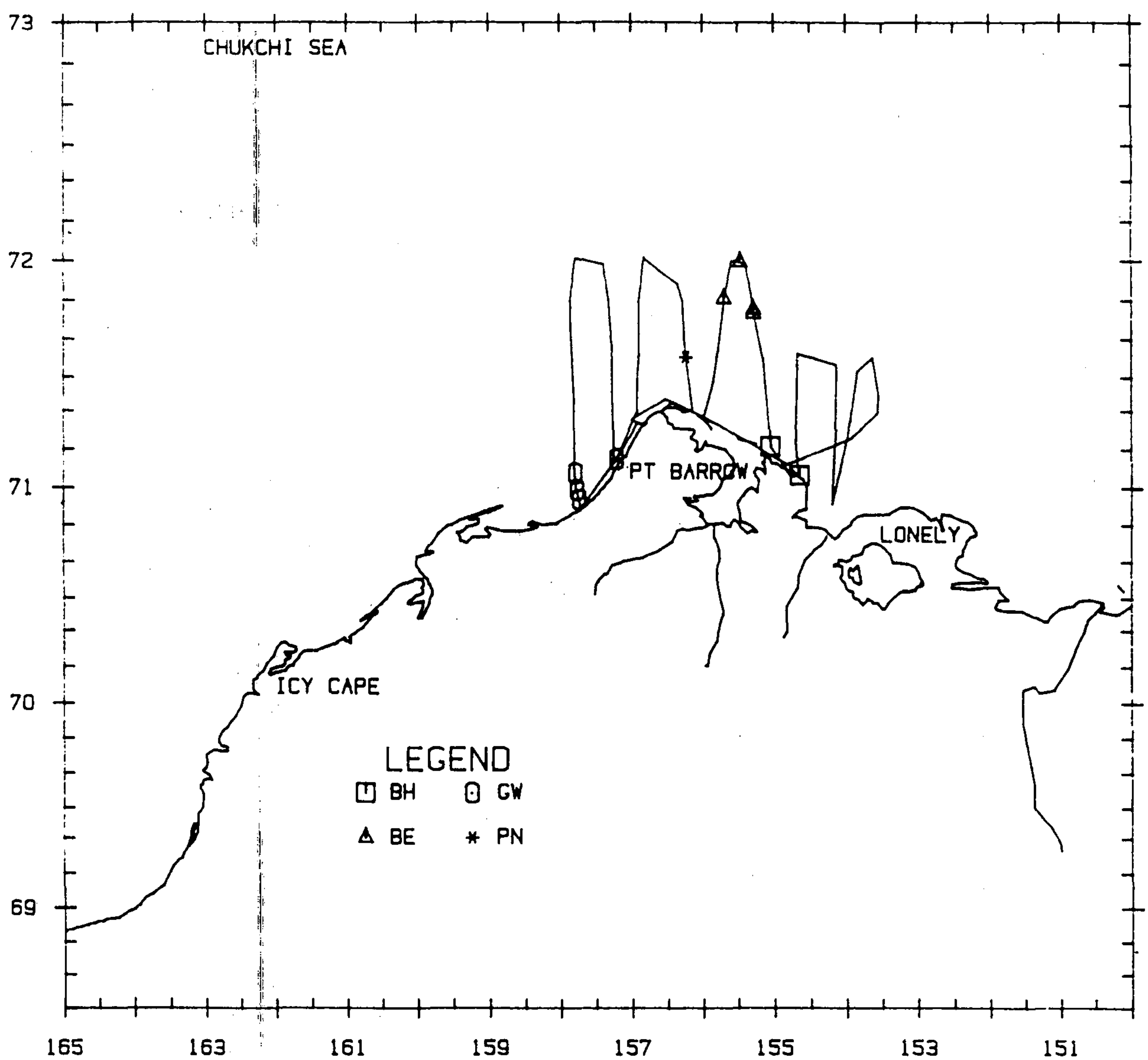


GRUMMAN GOOSE FLIGHT 15: 22 September 1987



GRUMMAN GOOSE FLIGHT 21: 30 September 1987

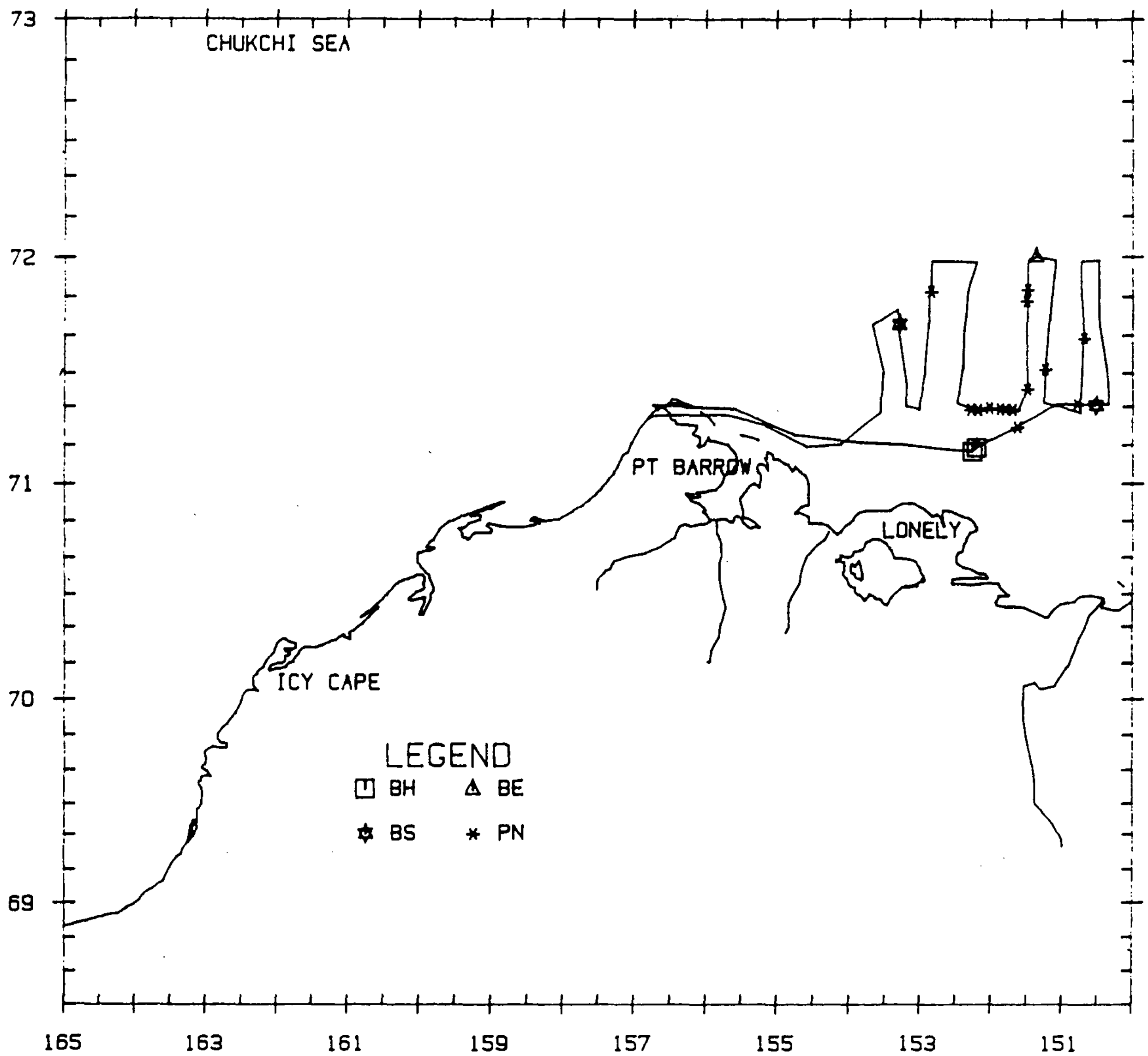
Endangered whales sighted west of 154°W. longitude are described by Ljungblad et al., 1988.



GRUMMAN GOOSE FLIGHT 24: 5 October 1987

Bowhead Whales

T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	71°09.4'	152°12.2'	-	BO	SW	240	0	B2	13
1/0	71°08.4'	152°15.7'	-	BO	SW	150	0	B2	13

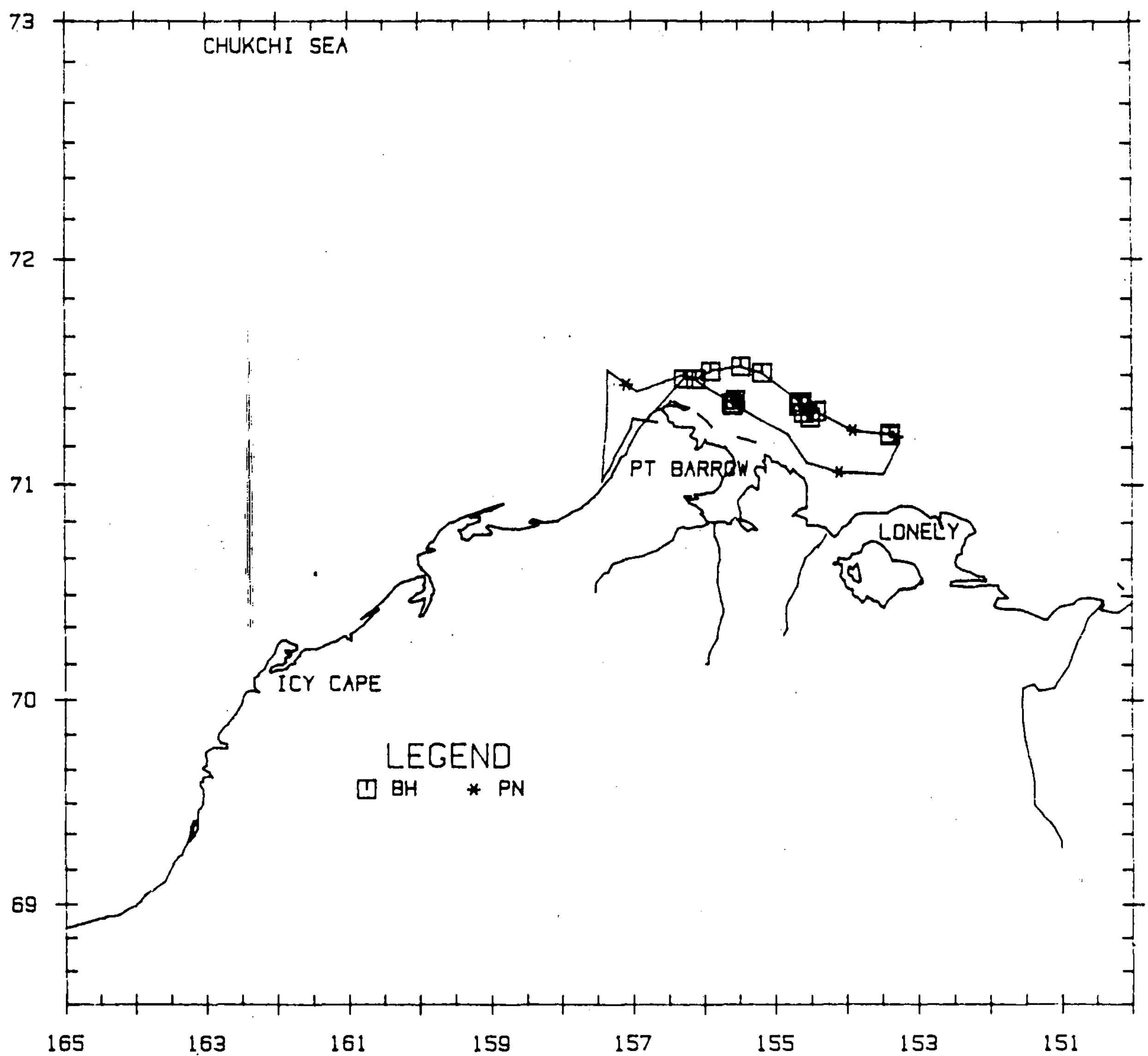


GRUMMAN GOOSE FLIGHT 25: 6 October 1987

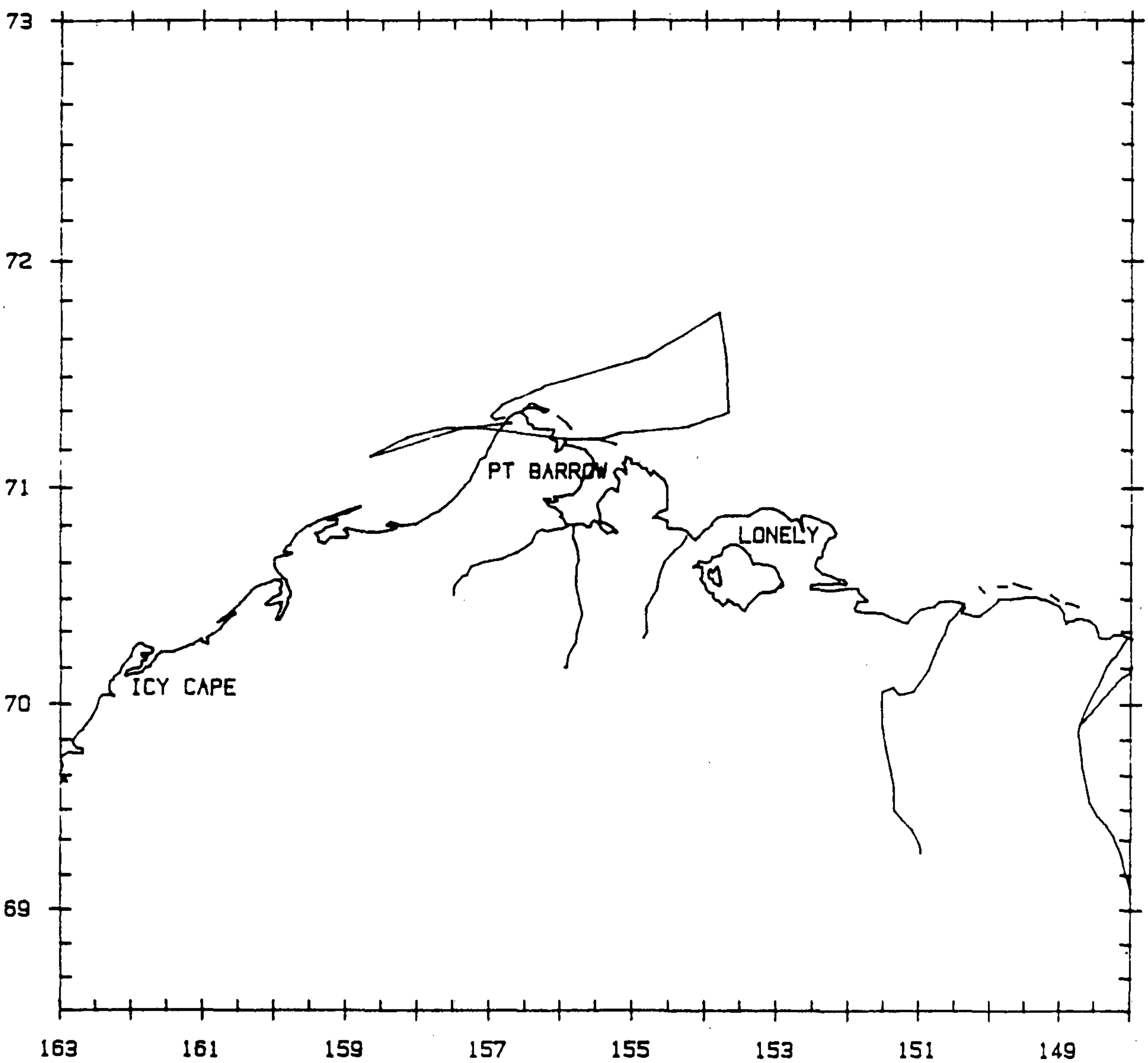
Bowhead Whales

T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
2/0	71°13.3'	153°22.2'	-	BO	SW	250	0	B2	22
2/0	71°13.7'	153°21.9'	-	BO	SW	260	0	B2	22

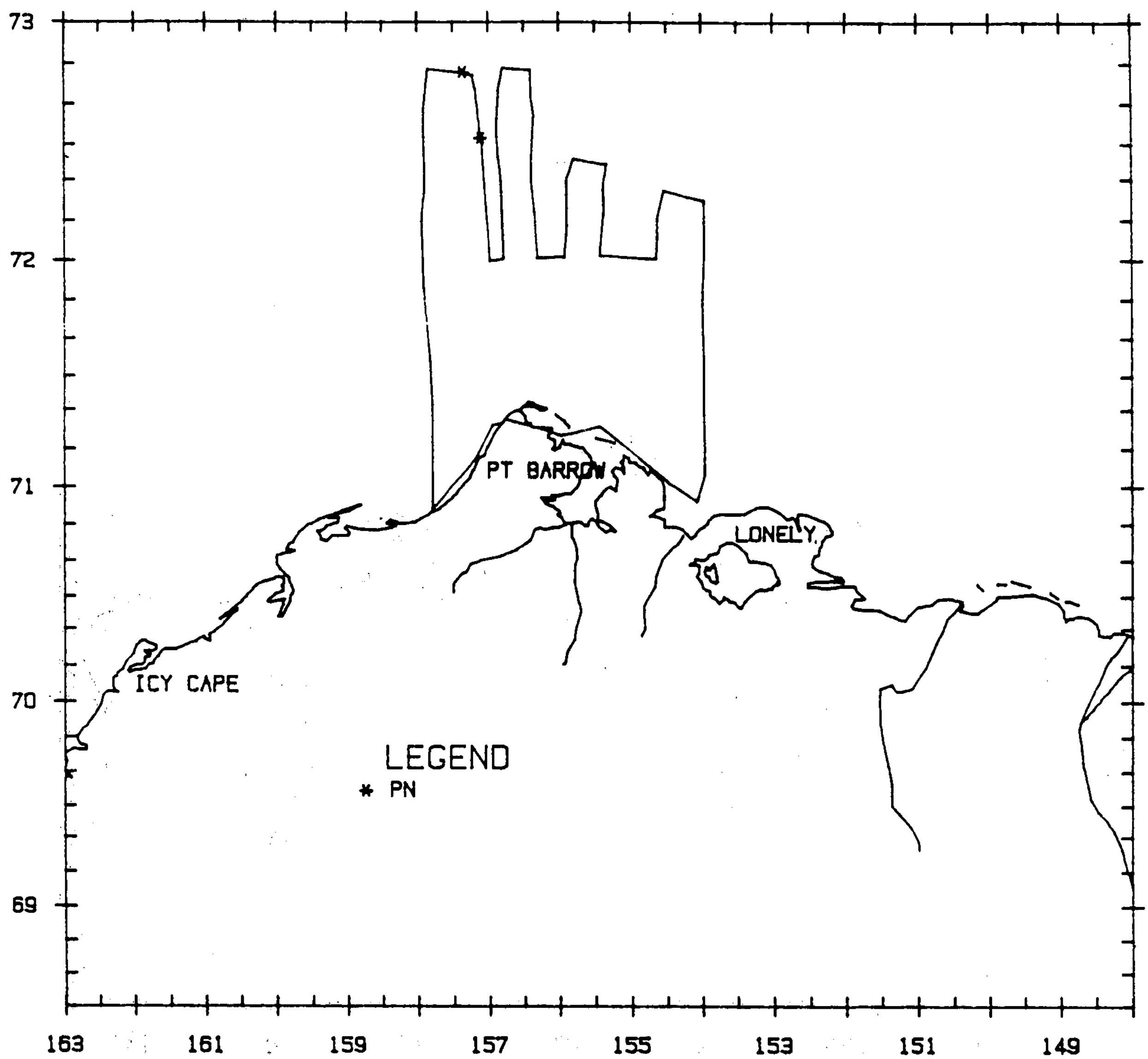
Bowhead whales sighted west of 154° W. longitude are described by Ljungblad et al., 1988.



GRUMMAN GOOSE FLIGHT 33: 19 October 1987

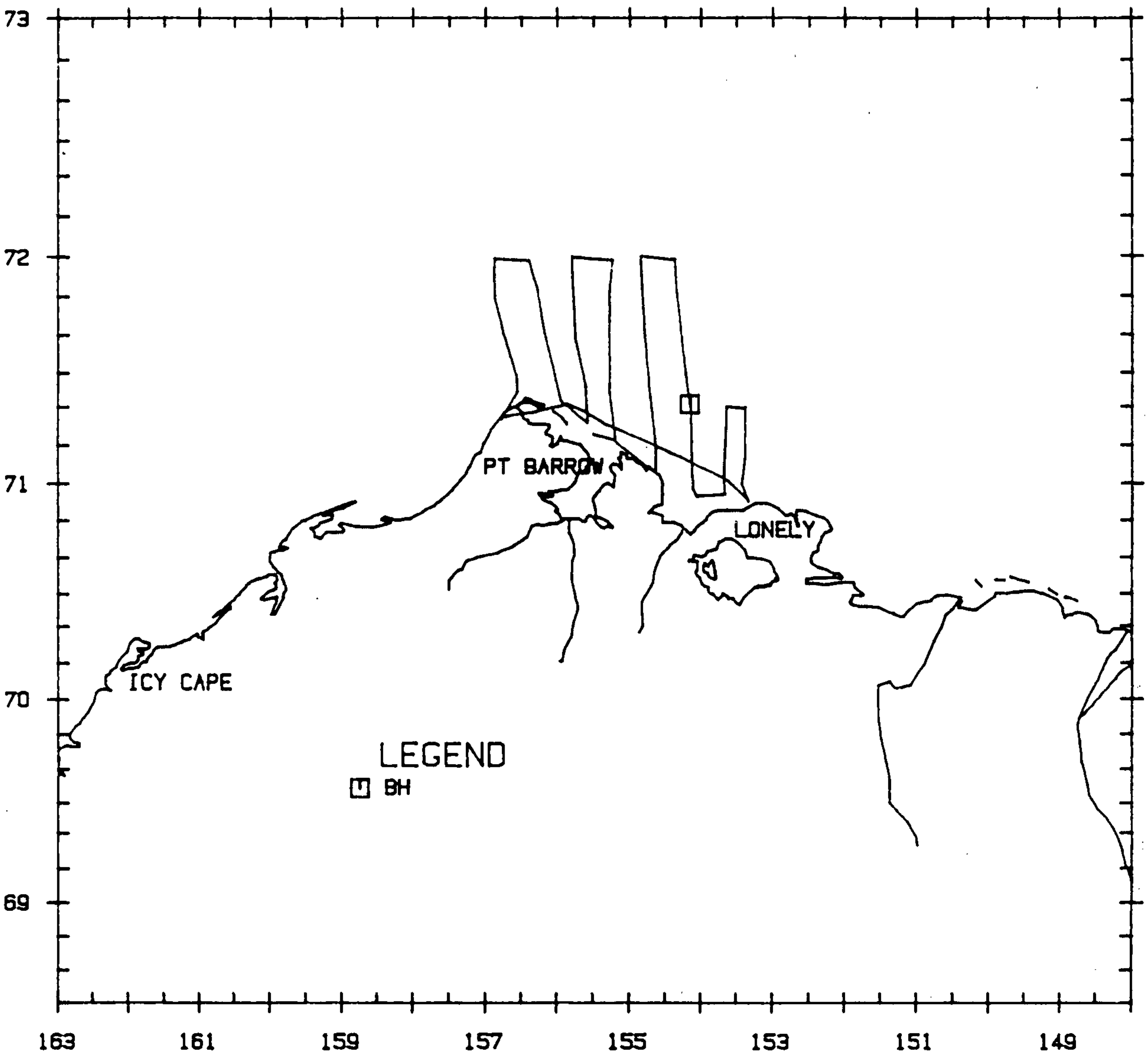


GRUMMAN GOOSE FLIGHT 35: 21 October 1987



GRUMMAN GOOSE FLIGHT 36: 23 October 1987

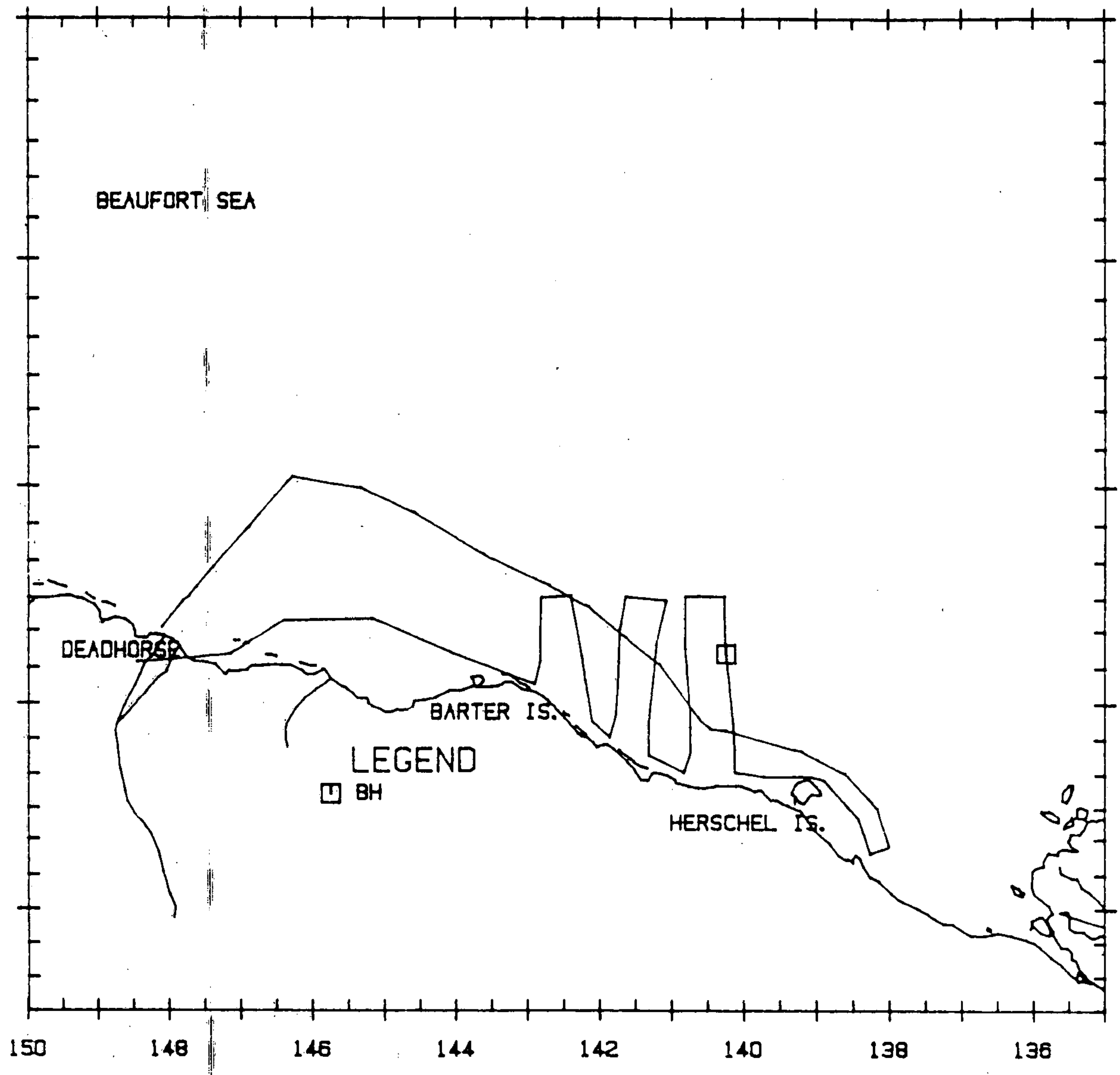
Bowhead whales sighted west of 154° W. longitude are described by Ljungblad et al., 1988.



GRUMMAN GOOSE FLiGHT 37: 25 October 1987

Bowhead Whale

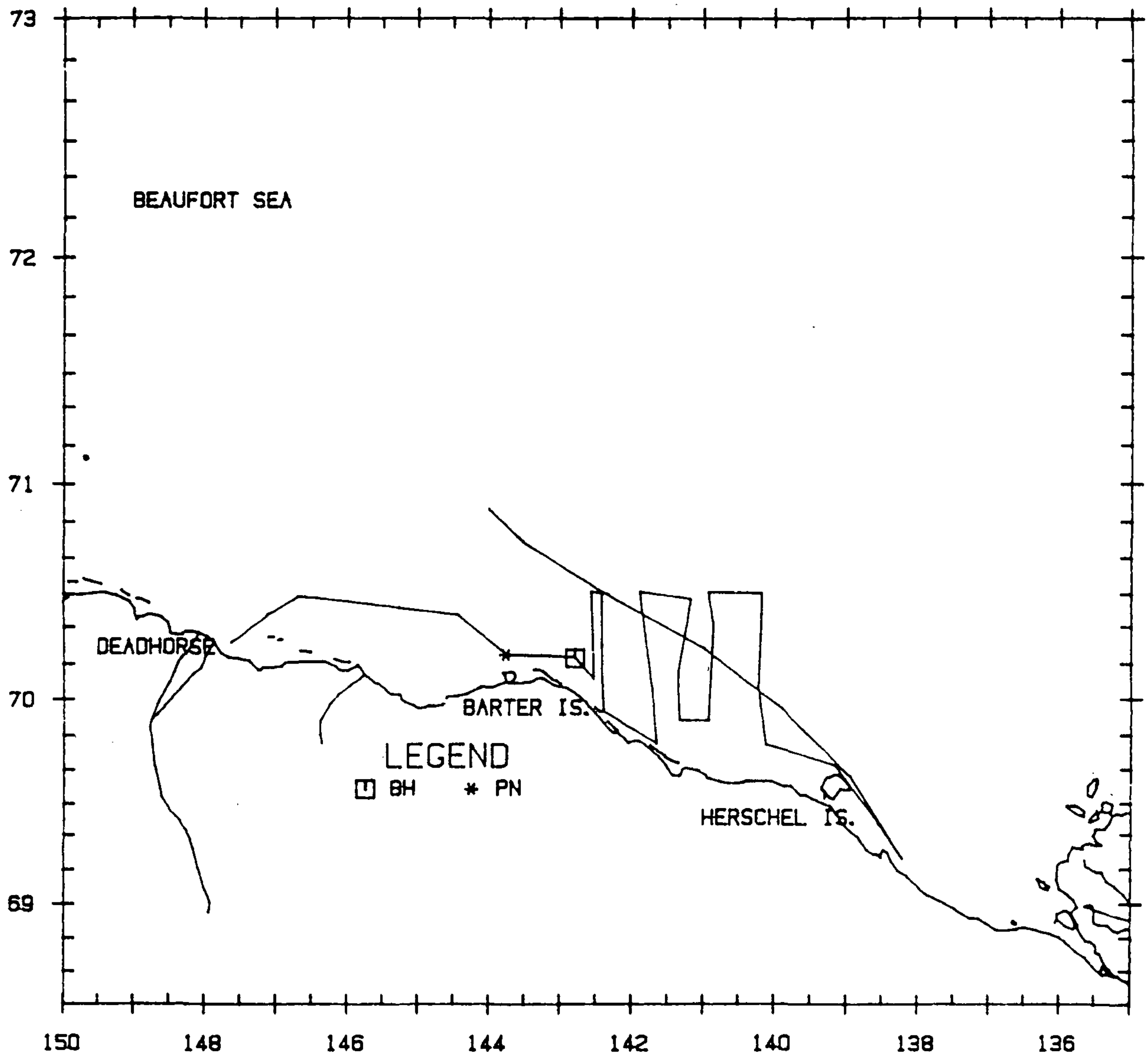
T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	70°13.8'	140°14.0'	1446	SP	SW	240	0	B2	62



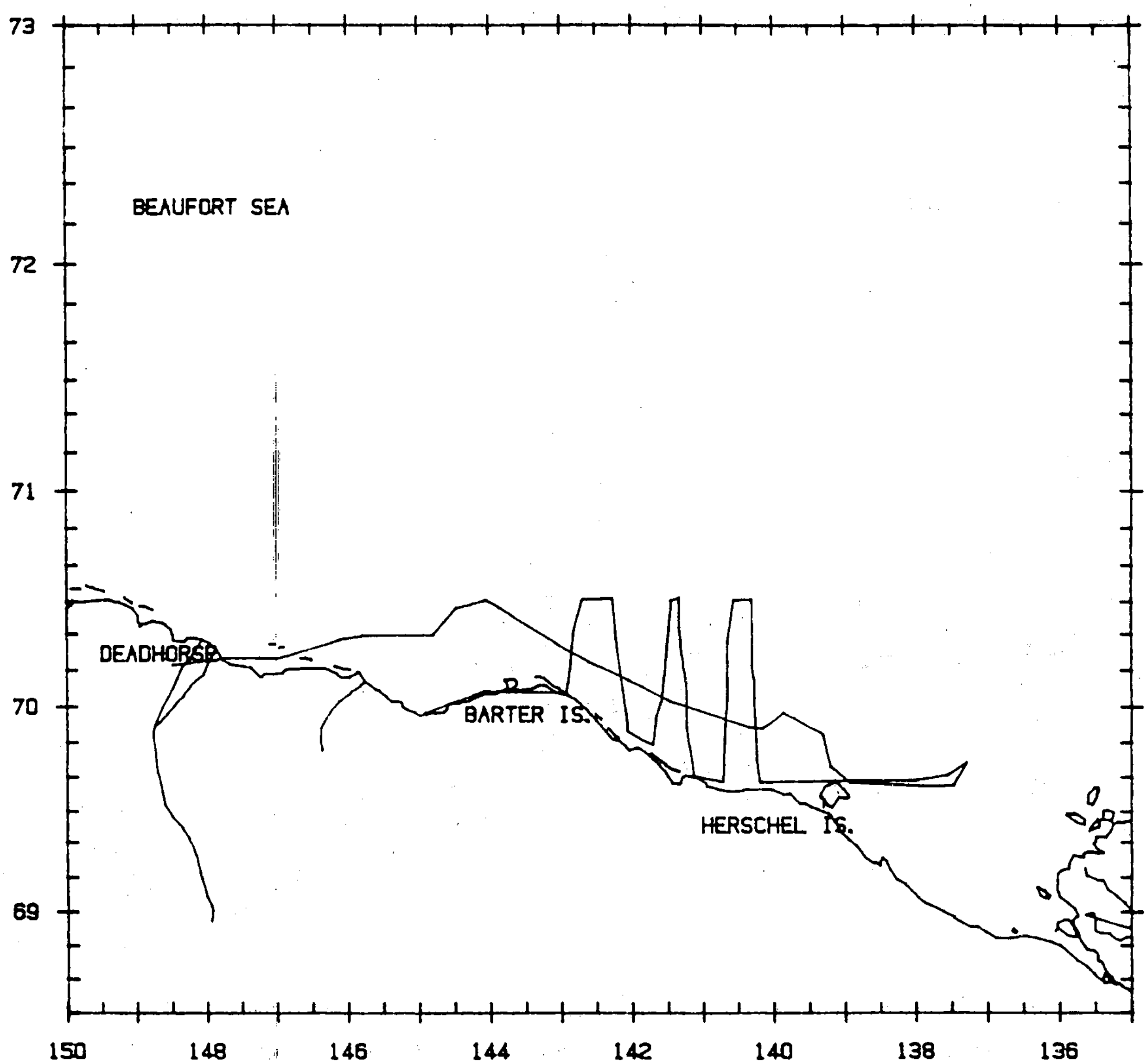
GRUMMAN GOOSE FLIGHT 38: 28 October 1987

Bowhead Whale

T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	70°11.6'	142°46.6'	1006	BO	SW	240	65	B1	22



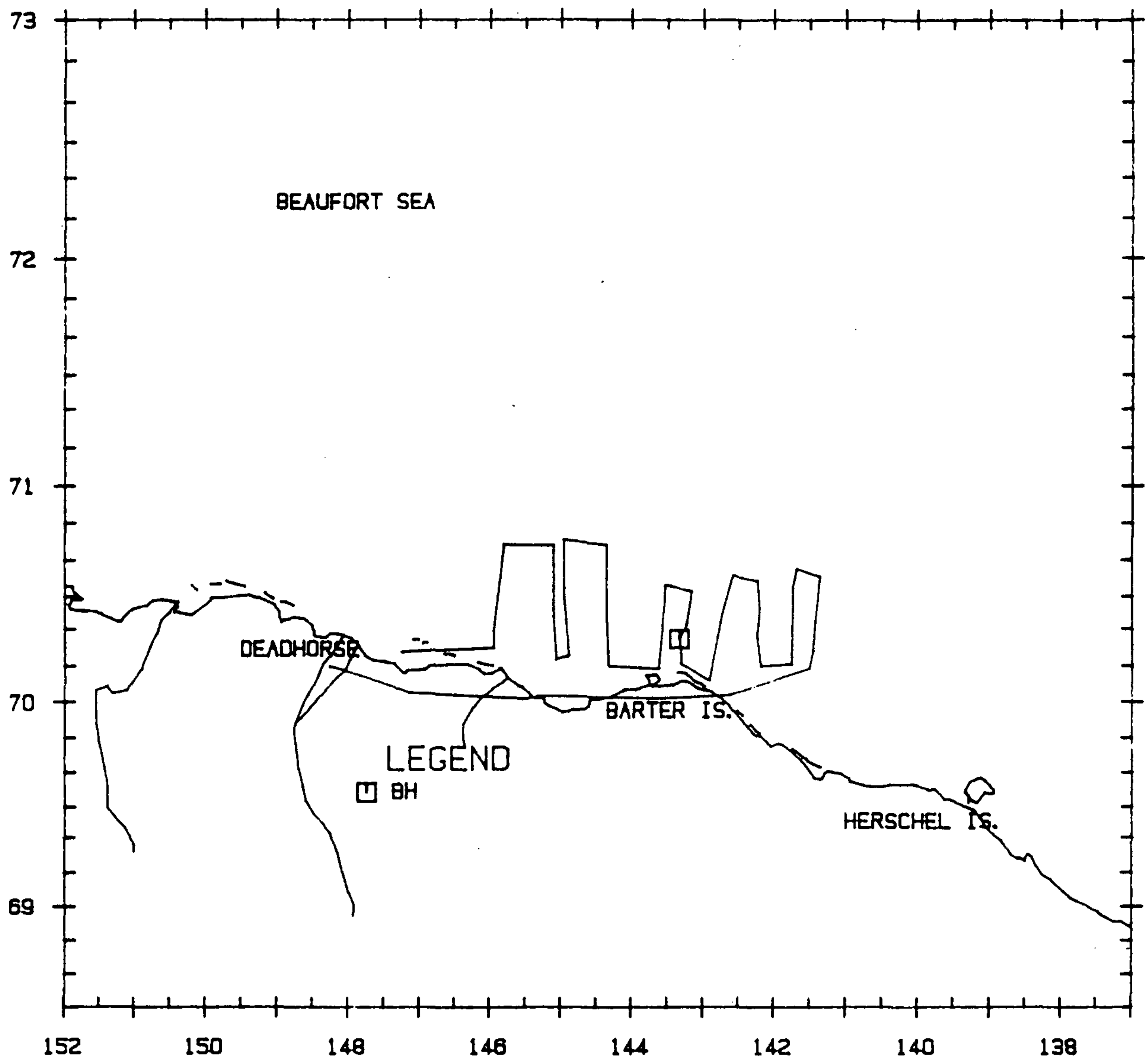
GRUMMAN GOOSE FLIGHT 39: 29 October 1987



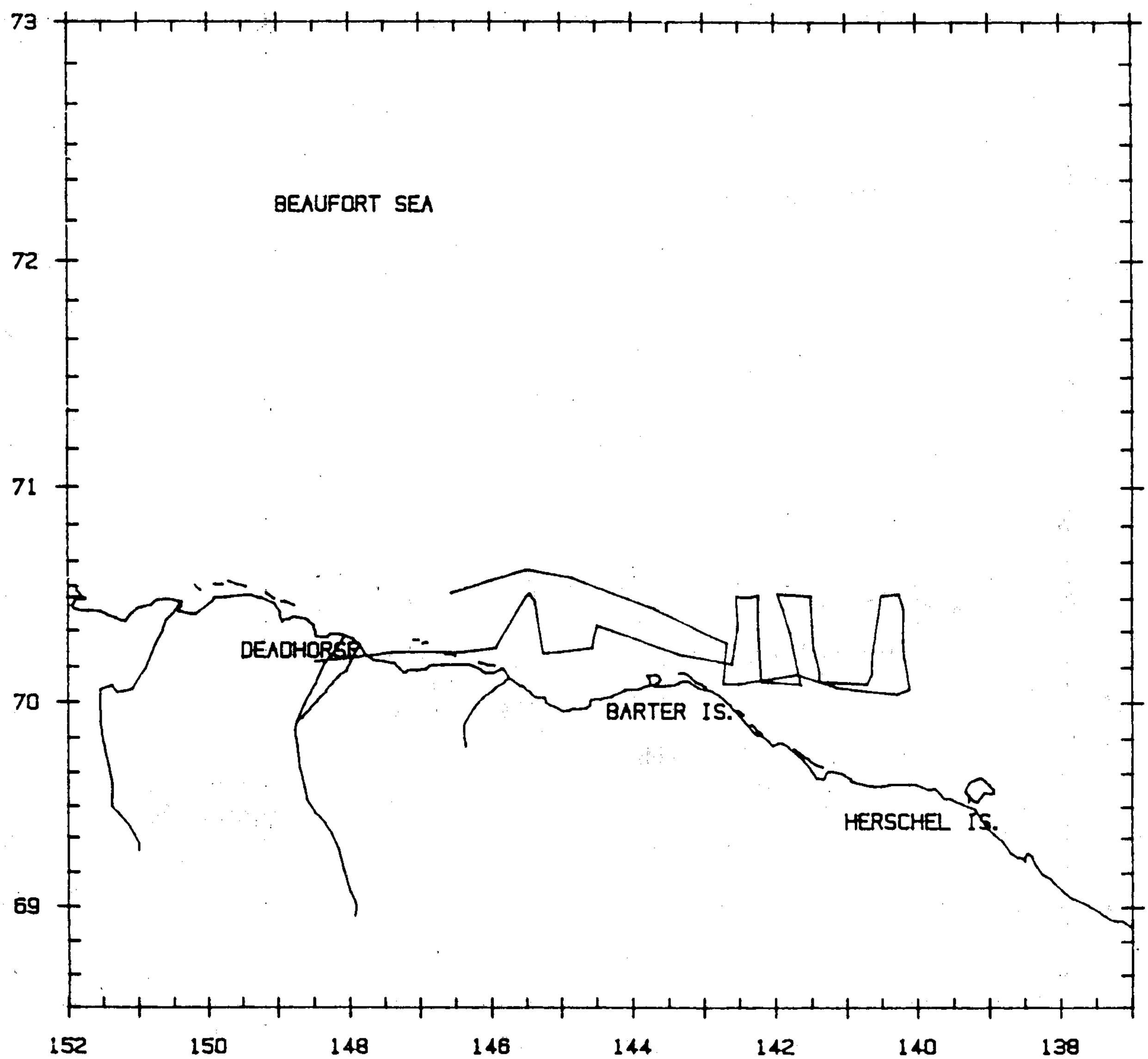
GRUMMAN GOOSE FLIGHT 40: 30 October 1987

Bowhead Whales

T#/C#	LAT	LONG	DIS	CUE	BEH	HDG	ICE	SS	DEPTH
1/0	70°17.5'	143°19.7'	-	BO	SW	240	5	B4	22



GRUMMAN GOOSE FLIGHT 41: 31 October 1987



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GLOSSARY OF ACRONYMS, INITIALISMS, AND ABBREVIATIONS

AMP	A Mapping Package
BLM	Bureau of Land Management
C	Celsius
CI	confidence interval
cm	centimeter
EIS	environmental impact statement
ESA	Endangered Species Act
GNS	Global Navigation System
h	hour
HP	Hewlett-Packard
km	kilometer
m	meter
MAT	an underwater mat or platform for the SSDC
min	minute
MMPA	Marine Mammal Protection Act
MMS	Minerals Management Service
NOAA	National Oceanic and Atmospheric Administration
NOSC	Naval Ocean Systems Center
NMFS	National Marine Fisheries Service
nmi	nautical miles
OAS	Office of Aircraft Services
OCS	Outer Continental Shelf
OCSEAP	Outer Continental Shelf Environmental Assessment Program
OCSLA	Outer Continental Shelf Lands Act
SD	standard deviation
SPUE	sightings per unit effort (number of whale sightings counted per hour)
SSDC	Single Steel Drilling Caisson
USDOC	U.S. Department of Commerce
USDOI	U.S. Department of the Interior
USGS	U.S. Geological Survey
WPUE	whales per unit effort (number of whales counted per hour)

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