Fall 1983 Beaufort Sea Seismic Monitoring and Bowhead Whale Behavior Studies

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SUMMARY

Geophysical vessel monitoring and bowhead whale behavioral observations in the western Beaufort Sea were carried out by crews aboard two aircraft, N642 and N655MA, from August 18 to September 30, 1983. Nineteen monitoring grids around geophysical vessels were completed during the 41 survey flights initiated by N642; 15 whales were sighted within the 2000 km^2 survey grid on 5 of these flights.

Behavioral observations were made while N642 and N655 MA circled over whales for 32.2 h, from 136°W to 154°W. Whales considered exposed to seismic sounds on six days were referred to as potentially disturbed (in the presence of seismic sounds), and detailed behavioral data was obtained on three of those days (September 8, 16, and 18). Number of blows per surfacing was significantly lower for potentially disturbed whales and blow intervals were not quite significantly longer for disturbed than for undisturbed whales. Neither surface nor dive time were significantly different between undisturbed and potentially disturbed whales.

Due to the heavy ice coverage which prevailed in 1983, bowhead whale/geophysical vessel interactions and controlled experiments could not be successfully completed. Nevertheless, behavioral data on undisturbed and predominately migrating bowheads were collected. Undisturbed bowheads were observed during 87.5% of the time (28.2 h). Summary statistics for undisturbed non-calves included 1261 blow intervals, 154 number of blows per surfacing, 168 surface times and 59 dive times. The mean blow interval was 14.4 $\pm$ s.d. 9.46s, mean number of blows per surfacing 5.6 $\pm$ s.d. 3.34, mean surface time 1.33 $\pm$ s.d. 1.095 min, and mean dive time 7.11 $\pm$ s.d. 5.943 min.

INTRODUCTION

The search for and recovery of oil resources in the Beaufort Sea has brought about the possibility of disturbance to the marine environment. Potential causes of acoustic disturbance are waterborne sounds generated by aircraft and vessel traffic, industrial noise from drill platforms and islands, and seismic survey signals originating from open-water geophysical vessels searching acoustically for evidence of oil deposits. The presence of geophysical and other industry-related sounds has led to increasing concern about the effects of such potential disturbance on resident and migrating stocks of marine mammals, in particular the endangered bowhead whale, Balaena mysticetus.

Bowhead whales migrate each spring during April to June from winter grounds in the Bering Sea to summer feeding grounds in the Canadian Beaufort Sea (Ljungblad, 1981; Ljungblad et al. 1980, 1982, 1983, 1984). The spring migration through the Alaskan Beaufort Sea is offshore and to the north of areas currently being considered for leasing for oil resources. Summer feeding grounds in the eastern Beaufort Sea, however, are within areas of industrial development in the search for and recovery of oil, via artificial islands and drillships (Richardson and Fraker, 1982; Richardson et al. 1983a). The Minerals Management Service (MMS) has funded research on the possible effects of industrial activity on feeding bowheads in the Canadian Beaufort Sea since 1980 (Fraker et al. 1982; Richardson et al. in press).

From August through October the bowheads migrate westward from the Canadian Beaufort Sea, through the Alaskan Beaufort and Chukchi Seas, finally returning to their wintering grounds in the Bering Sea. This migration has been monitored since 1979 by MMS-sponsored aerial surveys (Ljungblad, 1981; Ljungblad et al. 1980, 1982, 1983, 1984), and passes near or through areas which are currently being explored for oil resources or considered for oil leasing. The migration also coincides with the short open-water geophysical exploration season which is from August to early October in the Alaskan Beaufort Sea, placing migrating bowhead whales and operating geophysical vessels in the same general area each fall.

The sounds produced by geophysical vessels, originating from airgun arrays, are high pressure-level pulses of up to 248 decibels (dB) re 1 microPascal (Johnston and Cain, 1981, as cited in Fraker et al. 1982) at generally low frequency ranges of 10 - 200 Hertz (Hz) (Barger and Hamblen, 1980). Concern about the potential disturbance of bowhead whales by seismic survey signals has led to MMS-sponsored efforts to monitor geophysical vessel/bowhead whale interaction in areas of the Alaskan Beaufort Sea where bowheads are found during their fall migration.

Geophysical sounds in the presence of bowheads were first heard and recorded in the fall of 1979 during endangered whale surveys for the MMS (Ljungblad et al. 1980). In 1981, the MMS requested the Naval Ocean Systems Center (NOSC), San Diego, to monitor geophysical activities in the Alaskan Beaufort Sea in association with ongoing distribution surveys. Daily reports were provided to decision making officials who, based on the presence of whales, closed areas of the Alaskan Beaufort to geophysical operations. In the fall of 1982, the monitoring effort was expanded, and an additional aircraft and crew were dedicated to monitoring geophysical operations as well as collecting opportunistic behavioral data on bowheads in the presence and absence of geophysical sounds (Reeves et al. 1983). Daily reports were again communicated to appropriate officials, who regulated seismic operations by closing down areas of the Beaufort Sea to geophysical operations if whales were present and migrating through.

To date, the results of research into the effects of geophysical sounds on bowhead whale behavior have been inconclusive. In 1981, bowheads in the Canadian Beaufort Sea were observed on two occasions within 8 to 13 km of an active geophysical vessel which was using sleeve exploders, and the bowheads showed no conclusive evidence of alterations in surfacing and respiration characteristics when compared to whales in the absence of geophysical noise (Fraker et al. 1982). A degree of apparent tolerance to geophysical noise was also noted in 1981 in the Alaskan Beaufort Sea, when bowheads were observed within 14 km of an active geophysical vessel and did not exhibit any observable flight response from the area (DKL, pers. obs.). The 1982 studies in both the Alaskan and Canadian Beaufort Sea supported earlier findings that no avoidance reactions could be detected when bowheads were observed in the vicinity of active geophysical vessels (Reeves et al. 1983; Richardson et al. 1983b). However, these results are based on opportunistic observations, and are generally inconclusive.

By 1983, it had become clear that to answer the question of whether or not seismic sounds from geophysical exploration have a deleterious effect on bowheads, a controlled experimental approach was necessary. A conference, held in February of 1983 in San Diego, was convened and attended by representatives from industry, the federal government and the scientific community. The topics of interest at this meeting included the areas of the Beaufort Sea in which to conduct such experiments, and the experimental design. Although both the Alaskan Beaufort Sea and the Canadian Beaufort Sea were considered, it was agreed that for the results of experimental disturbance trials to be directly relevant to management needs, such trials should preferably be conducted:

a) in Alaskan waters where the potential problem resides,

b) at a time of year when the coincident use of these waters by migrating bowheads and geophysical vessels occurs, and

c) with a commercial geophysical vessel in full-scale operation.

In other words, the circumstances surrounding the trials must resemble as closely as possible those that exist in the normal industrial and biological context of concern. The experimental design and research protocol were developed through discussions among representatives of the MMS, member companies of the International Association of Geophysical Contractors, and the NOSC, the agency contracted to conduct the experiments and collect bowhead behavioral data in Alaska. Two geophysical companies, Western Geophysical Co. and Geophysical Service Inc., generously offered to make ship time available for this work, with the understanding that their participating vessels would operate under the direct guidance of the researchers. The plan, described under "Experimental Design and Research Protocol - N655MA", was to be implemented during the bowheads' fall migration through the Alaskan Beaufort Sea in September and early October 1983.

With these considerations in mind, the MMS provided three aircraft with crews in fall 1983: one dedicated to monitoring geophysical vessels in the Alaskan Beaufort Sea, as well as to making opportunistic observations of behavior (N642); the second dedicated to behavioral observations of bowheads and conducting experimental disturbance trials in cooperation with commercial geophysical vessels (N655 MA). In support of these two aircraft, measurements of waterborne seismic survey signals were to be obtained, under controlled conditions, from cooperating geophysical vessels operating in the Alaskan Beaufort Sea. The third aircraft (N780) was to be responsible for regional surveys to determine distribution, abundance, migration, and habitats of endangered whales in the northern Bering, eastern Chukchi, and Alaskan Beaufort Seas (see Ljungblad et al. 1984).

Unfortunately, exceptionally severe ice conditions during fall 1983 in the Alaskan Beaufort Sea frustrated attempts to conduct the experimental disturbance trials. There were few areas in the Alaskan Beaufort Sea sufficiently clear of ice that were accessible to geophysical vessels or within which safe and efficient geophysical operations were possible. The requirement that bowheads (the intended experimental subjects) be found in reasonably close proximity to a cooperating geophysical vessel (the intended stimulus), at a time when weather, availability of light, and other environmental conditions were suitable, could not be met.

Thus, this paper consists of the following:

1) a description of the methods used aboard the "monitoring" aircraft, Grumman Goose N642, to monitor geophysical activity, as well as the methods used to estimate rate of movement (swimming speed) of bowheads;

2) a description of the experimental design and research protocol intended to be employed with the dedicated "behavior" aircraft, Twin Otter N655MA, as well as a description of the methods used on both N655MA and N642 to collect data on bowhead behavior under conditions in which no experimental control was possible;

3) results of the monitoring effort, including estimations of swimming speeds and a description of ice conditions;

4) summaries of qualitative and quantitative data on bowhead behavior collected from both the dedicated "behavior" aircraft and the "monitoring" aircraft;

5) an analysis of the combined quantitative data from both aircraft;

6) in Appendix A, summaries and flight tracks for the flights by N642; and

7) in Appendix B, a description of methods and results of acoustic measurements of seismic survey signals obtained in the shallow Beaufort Sea, from a cooperating geophysical vessel.

MONITORING AND REGULATORY PROCEDURES

In fall of 1982, geophysical vessels operated under permits requiring them to shut down their seismic operations when:

(a) they were notified by the monitoring aircraft that bowheads within their "zone of influence", defined as 5.0 nautical miles (9.3 km), were potentially being disturbed,

(b) bowheads were sighted from the vessels, or

(c) officials of the MMS, after consultation with officials of the National Marine Fisheries Service (NMFS), determined that due to the presence of migrating bowheads, a given area was closed to seismic exploration (Reeves et al. 1983).

The permits under which offshore, open-water geophysical operations were conducted in 1983 differed from those issued in 1982 (information provided by the MMS). In 1983, part of the responsibility for monitoring bowhead distribution in the vicinity of seismic operations was assigned to the geophysical companies themselves. As a condition of their permits, the companies were required to post a whale lookout, equipped with standard field binoculars of 7 x 35 or higher power magnification, on board any vessel during the time that the seismic sound source was in operation. No airgun was to be discharged if an "endangered" whale (e.g. bowhead or gray whale, Eschrichtius robustus) was "within the lookout's range of vision."

In addition, the companies were required to submit monitoring plans for approval by the MMS, which would "ensure that endangered whales are not within 5.0 nautical miles of the vessel when the seismic sound source is operating". Such plans were to take effect after it was determined by the MMS that the bowhead migration had begun and that whales were "in the general area of the vessel". It was further stipulated that: "Whenever the monitoring becomes ineffective because of condition of available light, sea state, fog or other factors then the seismic sound source must be shut down until effective monitoring is reestablished". Both companies that conducted marine seismic operations in the Alaskan Beaufort Sea during September 1983 (Western Geophysical Co. and Geophysical Service Inc.) submitted acceptable monitoring plans and made extensive use of aircraft in implementing these plans.

METHODS

Field Procedures - N642 and N655MA

An amphibious Grumman Goose G21-C aircraft (N642) and a de Havilland Series 300 Twin Otter aircraft (N655MA) were used. Both aircraft have two turbo-prop engines and high wing configuration, and are equipped with observation "bubbles" to facilitate watching whales, radar altimeters for precise altitude information, and Global Navigation System 500A Series VLF computers (GNS500A) for navigation.

The aircraft and their respective crews of five or six (pilot, co-pilot, data recorder, two principal observers, and usually a video-camera operator) were based in Deadhorse, Alaska, near Prudhoe Bay (Figure 1). The Grumman Goose (N642) operated in the Alaskan Beaufort Sea in a geophysical vessel monitoring capacity from August 17 through September 30, 1983. The Twin Otter (N655MA) arrived on the north slope of Alaska on August 27 and remained through September 30 in support of the bowhead whale/geophysical vessel experimental disturbance trials.

A supply of sonobuoys was carried on board both aircraft. These units are designed to be deployed from the air and were used to monitor and record underwater sounds. Two types were used: AN/SSQ-41A and AN/SSQ-57A. Sounds received by the sonobuoy hydrophone were transmitted on VHF to a broadband receiver (Modified AN/USQ-42) onboard the aircraft and recorded on a dual track Nagra IV-SJ tape recorder or a Dual-Tracer Nakamichi 550 cassette recorder. The entire system has a frequency response of 25 Hz to 10 kHz. These sounds could be heard on the crew's earphones while simultaneously being recorded on one tape track. Sonobuoys were dropped near geophysical vessels to determine whether or not they were shooting. Sonobuoys were also dropped opportunistically near barges, supply vessels, ice, and whales to record waterborne noise.

Verbal notes were recorded on a Nagra IV-SJ reel-to-reel recorder, a Nakamichi 550 cassette recorder, or a Sony Comment cassette recorder, and all observers and the pilots were linked into the same communication system, so that all comments made on the airplanes were recorded for potential use.

Flight data were entered and stored on Tandy Radio Shack (TRS)-80 Model 100 portable computers, accessed to TRS computer Cassette Recorders CCR-81 and TRS Color Graphics Printers CGP-115. The computers were interfaced to the aircraft's GNS 500 for automatic input of entry number, time, latitude, and longitude, and to the radar altimeter for precise input of altitude.

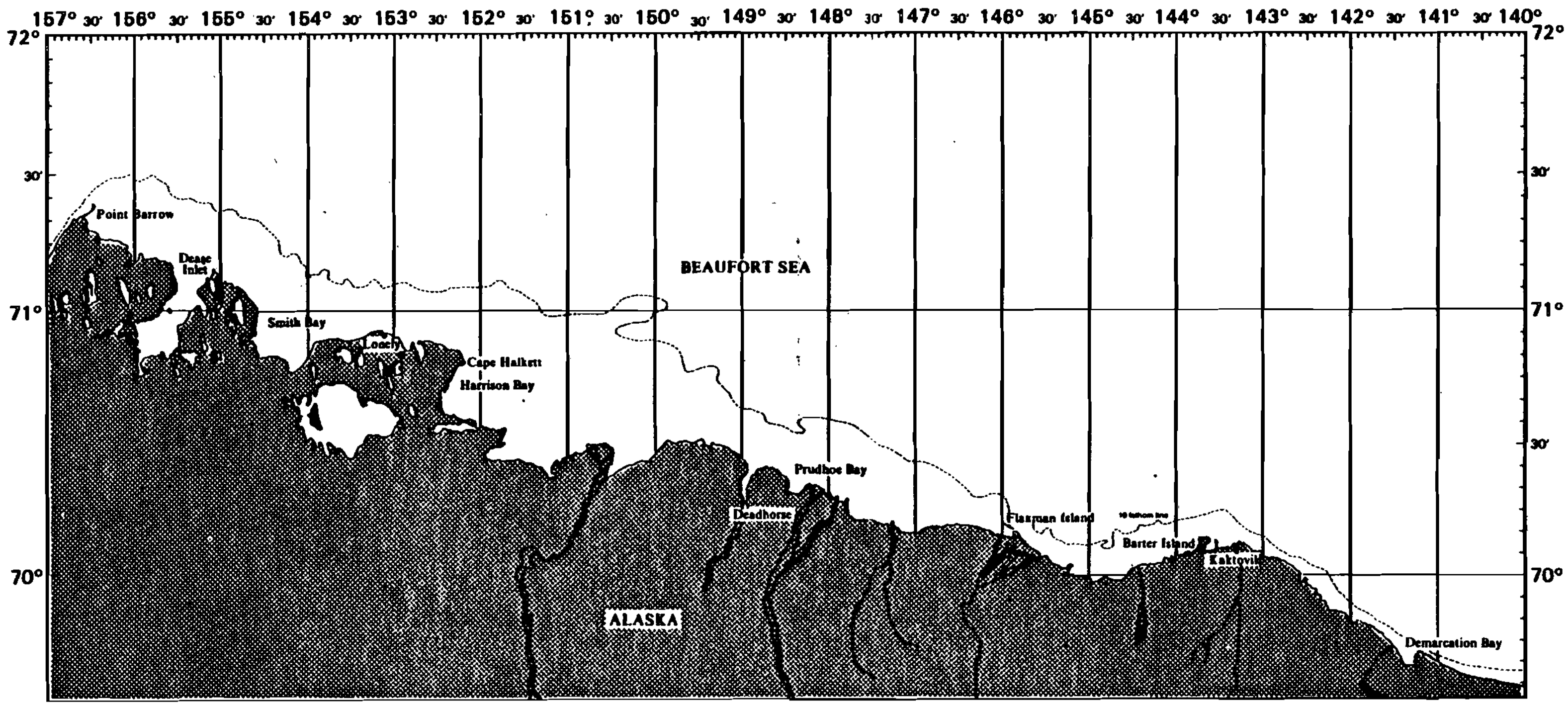


Figure 1. Study area in the Alaskan Beaufort Sea.

Three different data entry formats were available to the recorder: a full data sequence (29 entries), a weather update (15 entries), and a rapid sighting update (19 entries). One operator on each aircraft was responsible for entering data.

An on-site computing system was established at the base in Deadhorse. It consisted of a Hewlett-Packard (HP85) microcomputer, a dual-diskette drive, a printer/plotter, a printer, and a phone modem. The TRS data recording system was connected to the HP system for data transfer. Once transferred, the flight data could be checked for errors, and daily flight tracks could be mapped. After the sighting data were verified, they were put into a format on the microcomputer allowing them to be transferred, via phone modem, to the Arctic Environmental Information and Data Center in Anchorage. A narrative summary of the area surveyed and conditions encountered was also sent, via phone modem, to Anchorage daily. This system provided an efficient means of reviewing and checking data in the field, and it ensured a rapid flow of information to regulatory officials in Anchorage.

Additional equipment on board each aircraft included 35 mm single-lens reflex cameras with 70-210mm zoom lenses, Ektachrome ASA-200 color slide film, binoculars, clinometers, stopwatches, and a video recorder (Panasonic Omnipro) with a 75 mm lens (6:1 zoom ratio).

Monitoring Procedures - N642

The primary task of the crew on the Grumman Goose (N642) was to fly survey grids near seismic vessels to monitor the relative positions and distances of bowhead whales from geophysical vessels. Each day the morning position, operational status, and weather conditions for all active or potentially active geophysical vessels in the Beaufort Sea were obtained (Table 1). Geophysical exploration companies received this information by radio from their respective vessels and passed it on to us in-person or by telephone. This information was updated throughout the day, as the monitoring crew communicated regularly with the geophysical companies' base camps.

As in previous years, highest priority was assigned to vessels in the eastern portion of the study area. It was assumed that, particularly early in the season, the probability of encountering bowheads in this region would be higher than in the western portion of the study area. However, vessel operations were drastically affected by ice conditions in 1983. As a consequence, there was often little choice about which vessel to monitor first. On many days only one or two vessels were active, and for much of the season several vessels were in Canadian

Table 1. Morning position and daily operational status of geophysical survey vessels in the western Beaufort Sea, August 18 - September 24, 1983.
Source: personal communications from geophysical research companies - Western Geophysical Company of America and Geophysical Service, Inc.
(Note: the two right-most digits of the position are minutes; the left-most two or three digits are degrees). West Dock is at Deadhorse, Prudhoe Bay.

DATE (month/day 1983)

VESSEL		8/18	8/19	8/20	8/21	8/22	8/23	8/24	8/25	8/26	8/27	8/28	8/29	8/30	8/31	9/1	9/2	9/3
E.O. VETTER	A.M. Position Lat.N Long.W	Smith Bay	Smith Bay	Flaxman Island	Flaxman Island	70 30 142 00	70 25 142 44	70 26 142 33	70 12 141 59	70 33 142 10	70 39 142 10	70 32 141 39	70 07 141 32	70 33 139 58	70 11 140 20	70 17 141 13	70 04 139 30	69 59 139 01
	Shooting X = Yes O = No	O	O	O	X	O	O	X	X	X	X	X	X	X	X	X	X	X
ALASKAN	A.M. Position Lat.N Long.W	West Dock	West Dock	Flaxman Island	Flaxman Island	Flaxman Island	Barter Island	70 05 142 14	70 10 142 06	70 18 141 44	70 10 141 34	70 40 141 04	70 06 141 07	70 30 140 00	70 07 140 20	70 17 141 13	70 08 140 26	69 59 139 01
	Shooting X = Yes O = No	O	O	O	O	O	O	X	X	X	X	X	X	X	X	O	O	O
MARINER	A.M. Position Lat.N Long.W	70 17 141 48	70 08 141 43	70 01 138 57	69 47 139 55	70 15 142 00	70 15 142 02	70 07 140 24	70 14 137 47	Tuk	Tuk	Tuk	70 25 140 40	69 28 137 37	69 30 137 37	69 45 136 07	70 02 135 46	69 45 137 35
	Shooting X = Yes O = No	X	X	X	X	X	X	X	X	O	O	O	X	O	O	X	X	X
KRYSTAL SEA	A.M. Position Lat.N Long.W	Harrison Bay	70 38 150 14	70 34 150 38	70 34 150 38	70 33 150 15	Harrison Bay	Harrison Bay	Oliktok Point	Oliktok Point	70 40 151 27	70 39 151 26	70 50 151 26	Harrison Bay	Harrison Bay	70 36 151 11	70 44 151 18	70 38 151 24
	Shooting X = Yes O = No	O	O	O	O	O	O	O	O	O	X	X	X	X	X	X	X	X
WESTERN ALEUTIAN	A.M. Position Lat.N Long.W	70 10 143 40	70 28 144 25	70 07 144 26	70 42 143 01	70 26 143 35	70 33 144 28	70 31 143 35	70 34 143 03	70 28 142 40	70 24 141 56	70 26 141 24	70 14 141 33	70 05 140 50	70 11 140 20	70 11 140 00	70 08 138 31	70 31 139 52
	Shooting X = Yes O = No	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	O
ARCTIC STAR	A.M. Position Lat.N Long.W	Barter Island	70 20 143 00	Demarc. Bay	Demarc. Bay	Demarc. Bay	Demarc. Bay	70 27 140 33	70 07 140 30	70 15 142 30	Barter Island	Barter Island	70 38 141 05	70 10 140 45	70 11 140 20	70 11 141 45	Herschel Island	Herschel Island
	Shooting X = Yes O = No	O	O	O	X	X	X	X	X	X	X	X	X	X	X	X	O	O
WESTERN POLARIS	A.M. Position Lat. N Long.W	70 15 141 17	70 12 141 00	70 03 139 00	70 35 142 27	70 18 142 12	69 52 141 16	70 04 142 02	70 40 143 44	70 04 141 51	70 24 141 56	69 55 140 45	70 26 140 20	Herschel Island	70 11 140 20	70 19 140 14	69 33 137 55	70 04 139 22
	Shooting X = Yes O = No	X	X	X	X	X	X	X	X	X	X	X	O	O	X	O	O	O

Table 1 (cont).

9/4	9/5	9/6	9/7	9/8	9/9	9/10	9/11	9/12	9/13	9/14	9/15	9/16	9/17	9/18	9/19	9/20	9/21	9/22	9/23	9/24
70 09 138 34	70 15 139 03	69 56 138 27	70 00 139 00	70 33 140 37	70 19 142 40	70 15 145 39	70 29 147 17	70 27 147 35	70 27 147 12	70 27 147 17	70 05 145 05	70 07 142 56	West Dock	West Dock	71 05 153 51	71 22 155 44	71 14 157 17	71 06 157 41	71 06 157 41	Barrow
x	x	x	o	o	o	x	x	x	x	x	o	o	o	o	o	o	o	o	o	o
Tuk	6950 138 45	69 51 138 50	70 00 139 00	69 56 138 04	70 01 138 05	70 03 137 54	70 03 137 54	70 22 141 15	70 05 141 16	70 18 143 55	70 23 147 15	70 27 147 37	70 28 147 30	70 26 147 50	70 32 147 53	70 32 148 02	70 59 153 25	70 47 152 05	West Dock	West Dock
o	o	o	o	o	o	o	o	o	o	x	o	x	x	x	x	x	x	o	o	o
70 31 135 13	69 37 133 31	69 58 135 34	69 49 134 25	69 48 135 21	70 34 135 33	70 21 133 30	70 17 135 06	70 33 135 12	70 12 138 52	69 17 133 35	69 46 133 03	Tuk	Tuk	Tuk	Tuk	Tuk	Tuk	Tuk	Tuk	Tuk
x	x	o	o	o	x	x	x	x	x	o	o	o	o	o	o	o	o	o	o	o
70 45 151 27	70 41 151 20	70 38 151 08	West Dock	70 45 150 56	70 36 151 08	70 45 150 57	70 45 150 59	70 36 150 48	70 46 150 44	70 30 150 56	70 39 151 18	70 37 151 16	Harrison Bay	70 40 151 02	70 38 150 29	70 44 151 19	70 42 151 31	70 40 150 56	West Dock	West Dock
x	x	x	o	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	o	o
69 52 139 02	69 46 138 38	69 49 137 33	70 09 136 57	70 00 136 36	70 05 136 02	Pullen Island	70 17 137 33	70 21 141 15	70 06 141 14	70 07 144 50	70 30 147 40	70 13 145 35	70 14 145 26	Flaxman Island	70 32 148 47	70 29 148 00	70 09 144 57	70 09 144 11	70 06 145 20	West Dock
o	o	o	o	o	o	o	o	o	o	x	x	x	x	x	x	x	x	x	o	o
69 40 138 30	69 46 138 38	69 40 137 42	Kay Point	Thetus Bay	Herschel Island	Herschel Island	Herschel Island	Herschel Island	Herschel Island	Herschel Island	Herschel Island	Herschel Island	Herschel Island	Demarc Bay	70 15 145 09	70 05 144 30	Camden Bay	Camden Bay	Camden Bay	West Dock
o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	x	x	o	o	o	o
70 07 138 43	69 46 138 38	69 47 137 37	69 47 138 22	69 44 137 53	70 03 137 59	70 01 136 12	70 10 137 14	70 21 141 15	70 06 141 14	70 06 141 29	70 14 145 15	70 13 145 07	70 13 145 07	70 11 145 04	70 15 145 09	70 10 144 50	70 08 145 04	Camden Bay	Camden Bay	West Dock
o	o	o	o	o	o	o	o	o	o	x	x	x	x	x	x	x	x	o	o	o

waters, unable to move west because of severe ice conditions. On some days, several vessels were forced by ice to operate close to shore, where monitoring was more easily accomplished. Under these circumstances, decisions about how to allocate monitoring effort had to be made on more of an ad hoc basis than in 1982.

During August-October 1983, the crew aboard the third aircraft (Grumman Goose N780) performed broader regional surveys by flying sets of random north-south transects in 12 blocks covering the area bounded by the north coast of Alaska on the south, 72°N on the north, near the Canadian border on the east (140°W), and Pt. Barrow on the west (157°W) (Ljungblad, Moore and Van Schoik, 1984). Additional blocks in the Chukchi Sea included an area extending from Pt. Barrow south to Pt. Hope, west to the International Date Line and north to 73°N. This team's flight effort, which documented broad-scale distribution, relative density, migration timing and habitat use of endangered species (principally bowhead and gray whales), began July 31, 1983, and continued to October 19, 1983. Bowhead sightings made by this study team were reported daily to the monitoring and behavioral studies crews and also to appropriate Federal officials in Anchorage. This information helped direct decisions about where to concentrate the monitoring and behavioral study efforts.

Bowheads sighted by industry personnel, either from supply helicopters, ice reconnaissance planes, or vessels, were reported daily to the monitoring crew by the companies (Table 2). This information aided in determining where to focus study efforts. The monitoring crew generally preceded the behavioral studies crew into the field, attempting to locate whales while enroute to a vessel. If whales were located, their position was relayed via VHF radio to the behavioral studies crew on board N655MA.

Once a vessel was selected for monitoring, it was located visually and a series of systematic transects were initiated covering approximately 2000 km^2 near the vessel (Figure 2). The first transect in the grid was an 18.5 km line oriented north-south, beginning at the vessel's position when initially sighted. The second transect was a 37 km line parallel to the first, 4.5 km west of the vessel. Subsequent transects were also parallel to the first and 37 km in length, but moved progressively eastward at 9 km intervals. This grid pattern allowed the area immediately adjacent to the vessel to be surveyed and enhanced chances of intercepting relatively "unexposed" whales as they approached the sound source from the east (in fall, the migration passes from the east to west). Transect lines

Table 2. Whale sightings reported by geophysical companies - Fall 1983.

Date	Position	Time	Total No. of Whales	Heading of Whales	Vessel/Aircraft Reporting	Company	Comment
Aug 19	70°42.7'N, 143°49'W	1700	4	-	Western Aleutian	Western Geophysical	Vessel shooting
Aug 20	70°13'N, 141°10'W	-	2	-	-	Western Geophysical	Vessel not shooting
Aug 24	70°27'N, 140°33'W	1245	1	-	Arctic Star	Western Geophysical	Vessel in transit
Aug 24	70°11'N, 140°47'W	1720	1	-	Arctic Star	Western Geophysical	Vessel in transit
Aug 25	70°07'N, 140°30'W	0710	"pod"	-	Arctic Star	Western Geophysical	-
Aug 27	69°56'N, 139°49'W	1921	2	-	Air Log 13 Cessna Titan	Western Geophysical	-
Sep 2	69°39'N, 138°26'W	1800	5	330°	Western Polaris	Western Geophysical	-
Sep 4	69°40'N, 138°30'W	0750	2	330°	Arctic Star	Western Geophysical	-
Sep 9	70°00.8'N, 137°50'W	1730	2	240°	Western Polaris	Western Geophysical	Vessel not shooting
Sep 19	71°35'N, 154°56'W	1900	1	-	Air Log 71 helicopter	Geophysical Service Inc.	-
Sep 19	71°32'N, 155°35'W	-	1(?)	-	Air Log 71 helicopter	Geophysical Service Inc.	Possible whale

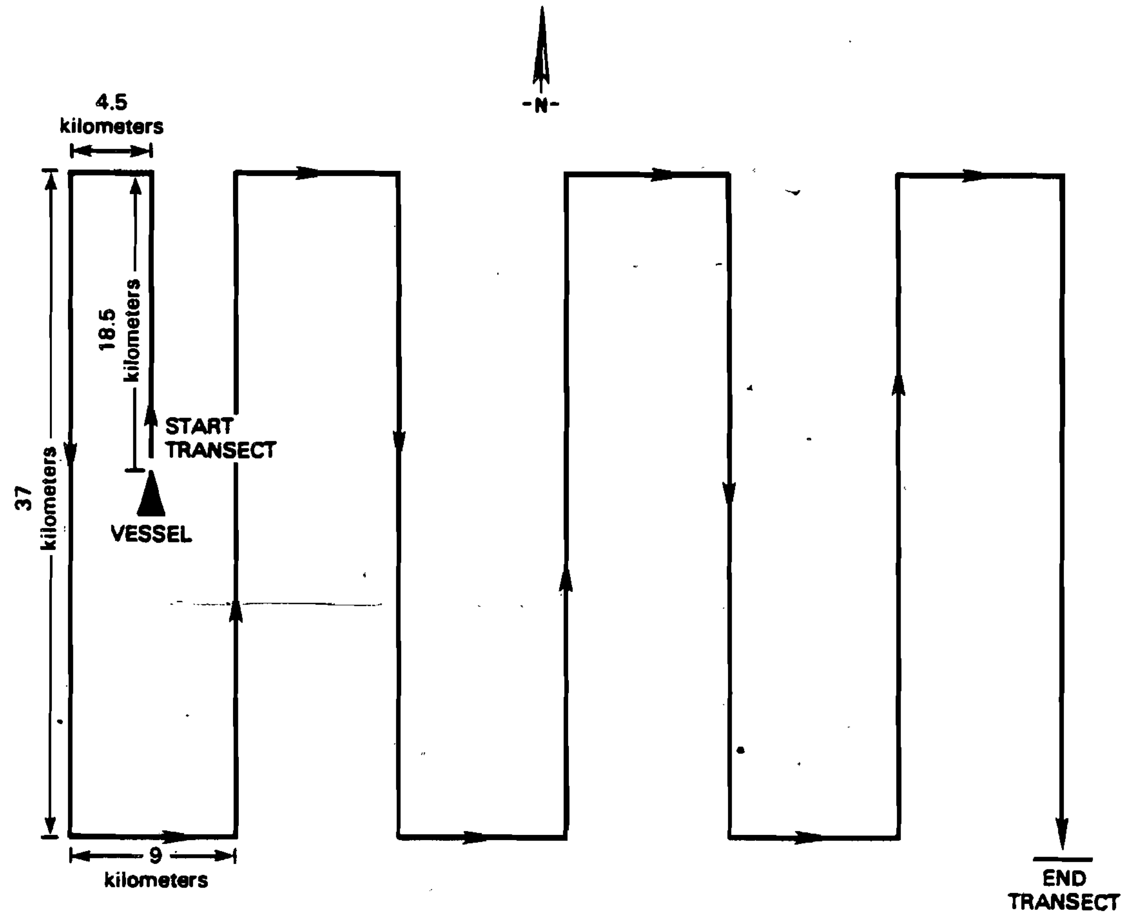


Figure 2. Systematic transect survey grid flown by N642, Fall 1983.

were occasionally modified due to local fog and snow flurries, and were sometimes truncated to avoid flying over land.

Standard observation procedures when flying transects were for one principal observer to be stationed at a bubble window on each side of the aircraft, maintaining a continuous watch. All members of the crew, as well as occasional official guests on board, contributed to the watch for whales. Although a surveying altitude of about 460 m was preferred, cloud ceiling and other weather conditions sometimes dictated a lower surveying altitude. An airspeed of about 130 knots (241 km/hr) was maintained while surveying, and somewhat slower speeds while circling. The primary considerations in deciding whether or not to fly were safety and visibility; wind speed and sea state were secondary considerations. As a result, flights were occasionally attempted when conditions on the sea surface were suboptimal for detecting and observing whales. Poor or marginal weather conditions, aircraft maintenance requirements, and decreasing day length were factors limiting total observation time.

Detection of whales enroute to vessel positions and along the 277 linear km grid in the vicinity of active geophysical survey vessels was regarded as high priority. Thus, whales seen on transect were not circled for long periods of time. Rather, whale positions were noted and reported to the crew of N655MA. Opportunities to observe unexposed (undisturbed) whales immediately before or after a geophysical survey vessel was shooting were also considered a high priority. However, opportunities to observe undisturbed whales in the vicinity of geophysical vessels rarely occurred in 1983. When no whales were sighted during the grid surveys, the flight effort was directed at searching for whales in areas of open water. On days when vessel monitoring was not possible or desirable, for example when no vessels were operating, or when local weather conditions made it impossible to fly safely in the vicinity of vessels, the monitoring aircraft flew search or transect surveys to find whales.

Experimental Design and Research Protocol - N655MA

The following limitations and concerns were specified in permit number 263, issued for this work by the Secretary of Commerce under the Marine Mammal Protection Act and the Endangered Species Act.

A major question to be addressed by the behavior and controlled experiment studies was: "At what distance from an active geophysical vessel are avoidance behavior or other manifestations of disturbance likely to be displayed by bowheads?" The answer would help define a "zone of influence" that presumably exists around any source of low-frequency, high-energy seismic sounds.

The objectives of the study as outlined in the National Marine Fisheries Service Permit to Take Endangered Marine Mammals No. 459, then, were:

1. To quantify the distance at which bowhead whales display an avoidance or other reaction to an operating geophysical vessel.
2. To replicate experiments, as possible and as judged advisable through incremental field or laboratory analyses of new data.
3. To provide information to government representatives as background for decision-making processes.
4. To assess, through synthesis with appropriate sources of information, the biological significance of observed effects (if any) for individual whales and for the whale population.

Subordinate objectives of (1) above were:

(a) To quantify surfacing, diving, respiration, rate of movement, direction of movement, vocalizations, and other behavioral parameters of bowheads while they were being directly approached by an operating geophysical vessel or vessels.

(b) To quantify variables associated with the stimulus or stimuli of concern, such as vessel movement, vessel direction from whales, airgun array size and configuration, acoustic source level, frequency, and pulse rate, received (near whales) sound level and frequency, as well as environmental correlates such as water depth, time of day, ice proximity and characteristics, sea state, and aircraft altitude.

(c) To determine and describe the degree of association (statistically, graphically, and qualitatively) between bowhead whale behavior parameters and relevant independent variables (see a and b above).

Objective 1 and its subordinate objectives (a-c) were motivated by the generalized null hypothesis to be tested:

"There is no change in bowhead behavior as related to distance from a moving, fully operating ('shooting') geophysical vessel."

Assuming the distance (D) of a vessel from a whale or group of whales at a point in time can be expressed as an interval level measurement, the following subordinate null hypotheses were to be tested:

Changes in D do not result in changes of bowhead whale

a. rate of movement,
b. direction of movement,
c. average surface time,
d. average blow intervals,
e. average number of blows per surfacing,
f. average dive time, and
g. there is no change in major qualitative behavioral mode (e.g. change from skim feeding to water-column feeding, water-column feeding to echelon feeding, echelon feeding to dispersal, etc.).

Since received levels of acoustic measures are related to changes in D, the major acoustic measures could be substituted and analyzed for their degree of covariant association with behavioral measures. Once testing of general hypotheses had been addressed, additional hypotheses or comparisons could have been made. For instance, it might have been instructive to make controlled comparisons of animal behavior at significantly different water depths, proximity to ice, change in vessel operational characteristics, or difference between major behavioral modes (e.g. migrating vs. feeding).

The general approach for meeting the objectives and testing the hypotheses listed above was to place an aircraft and crew in the field to (1) locate bowhead whales, (2) observe and measure whale behavior, acoustic and environmental variables, and (3) exercise control, via radio communication, over the movement and operational status of cooperating geophysical vessels during proposed experiments. It was our intention to subject the behavioral and acoustic data to preliminary analysis and to provide results, along with field interpretations, to the MMS in Anchorage on a daily basis.

The field conditions necessary for experiment initiation constituted an important limiting factor. Experiments could be attempted only during conditions of adequate visibility (little or no fog and a sea state of less than Beaufort 3), safe aircraft operation, "manageable" numbers of whales, minimal potential aircraft noise interference, and close proximity to an operational geophysical vessel which would become temporarily dedicated to the experiment. Also, the trials could only be performed within the limits of standard operation procedures and safety requirements of vessel operators. Aircraft would be required to fly at altitudes greater than 460 m, so cloud ceilings would have to exceed that altitude. In the initial replications, whale group size was not to exceed five or six animals, as it was thought that the reliability of the data would suffer if larger groups were being watched. In later replications, the group-size criterion may have changed as the emphasis on data collection shifted from respiratory parameters to those not necessarily tied to the repeated recognition of individual animals.

Arrangements were made in advance of the field season for the research teams on board N655MA and N642 to establish direct, VHF, and marine-band radio communications with the seismic vessels working in the Alaskan Beaufort Sea. In addition, the research teams were to communicate daily with the base camps of Western Geophysical Co. and Geophysical Service Inc. located in Deadhorse. This close coordination and communication between the aerial research teams and the cooperating geophysical companies was to provide reasonable notice to vessel operators of when and where a disturbance trial might be initiated. Whenever the necessary field test conditions were met (see above), the operator of a vessel near the whales under observation was to be notified by the principal investigator aboard the behavior aircraft (N655MA) and would be requested to move and operate as directed under permit #263 during the experimental mode. Both parties were to log the time of any request to move a participating vessel involved in the disturbance experiments as well as the time of termination of these experiments.

The primary mode of data acquisition was to guide a dedicated vessel conducting full-scale seismic operations directly toward bowhead whales (Table 3; protocol 1; Figure 3). Because of potential problems of interpretation in multi-vessel or multi-sound source experiments, the initial trials were to involve only one vessel at a time. Single or multi-vessel tangential approaches would also be realistic models to test, but would be more difficult to analyze and interpret (Table 3; protocol 2 and 3).

A "pre-exposure", "exposure", and "post-exposure" data classification was also considered desirable (Table 3; protocol 4), although it was understood that this ideal would not necessarily be achieved in every case, since the vessel(s) used in a given experiment could already have been shooting in close proximity to subject whales before receiving notification from the research team. Although less desirable, a simple "no stimulus" vs. "stimulus" comparison could have been

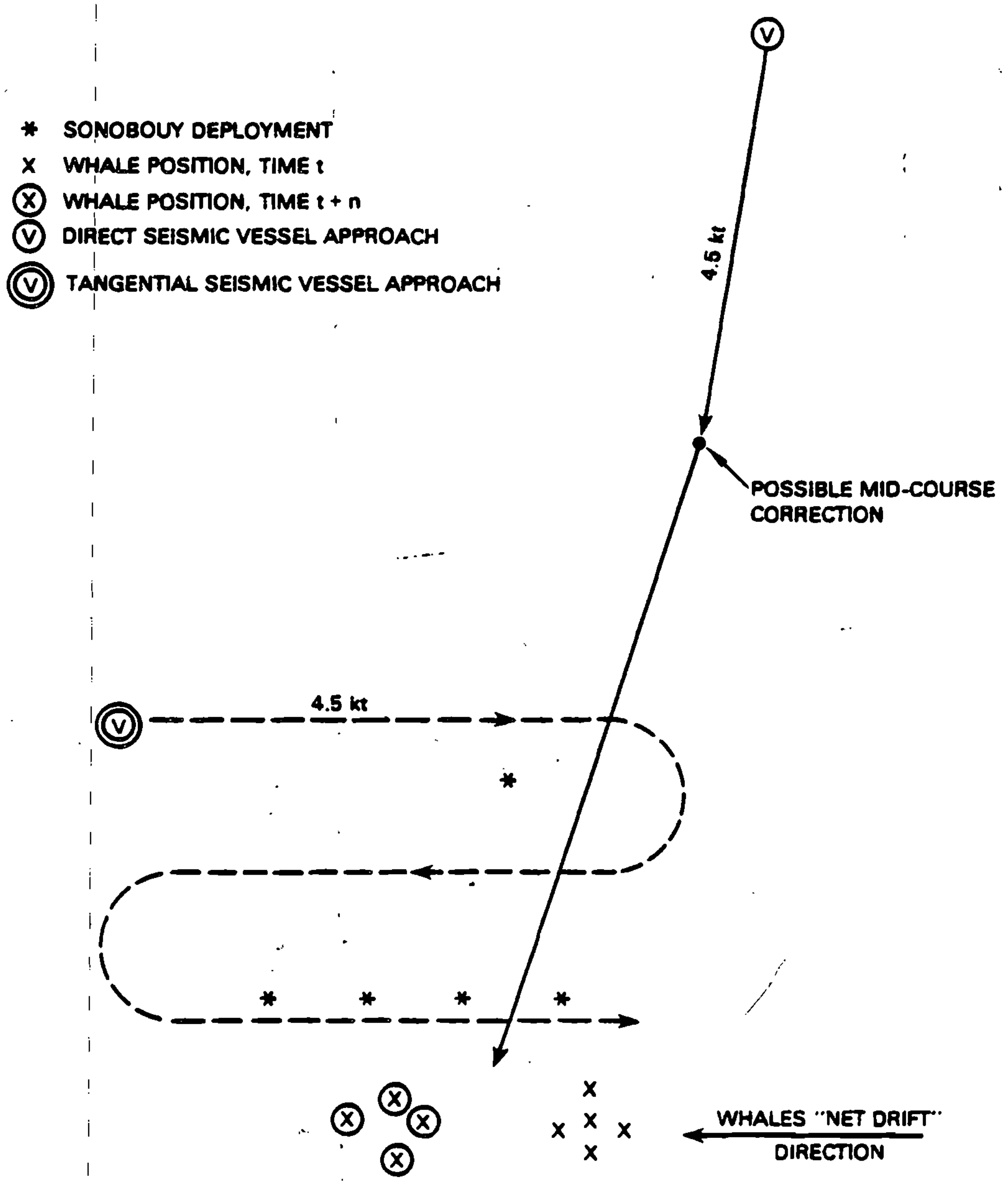


Figure 3. Proposed primary mode of data acquisition using a dedicated vessel.

Table 3. Initial experimental protocol and replicates.

Protocol No. & Priority	Vessel Approach	Seismic Sound Source	No. Vessels[1]	Minimum No. Replicates
1	Direct	Array operational during all phases	1	2-3
2	Tangential, with gradual range closure	Continual, all phases	1	1-2
3	Tangential, with gradual range closure	Continual, all phases non-synchronous arrays	2-3	1-2
4	Direct	Arrays silent during pre-exposure vessel positioning. Array operational during direct approach, gradual shutdown during "post-exposure" and withdrawal phase	1	2

[1]Number of vessels under guidance of the Principal Investigator.

made in the event that vessels near whales were intitially not shooting. One difficulty of such a design, however, would be separation of effects due to the novelty of a stimulus as opposed to tolerance of or habituation to a sustained stimulus. This sort of comparison would nevertheless be useful because vessels do shut down and start up their sound-source (airgun arrays) during the course of normal exploration activities.

Priorities of experimental protocols with preliminary estimates of the number of replications needed to gain preliminary statistical confidence and predictive application are shown in Table 3. Since substantial interest exists regarding possible differences between feeding and migrating whales, the protocols listed in Table 3 could be replicated for each of these two behavioral modes, potentially resulting in a maximum of 18 different experiments.

Mitigation of Potential Adverse Effects - N655MA

Seismic vessels were not to approach closer than within 1 km of whales during the proposed experiments. Since bowheads were observed to move away from a rapidly approaching (12.5 km per h), non-shooting geophysical vessel at a range of 1.0-2.8 km during experiments in 1981 (Fraker et al. 1982), it is possible that the animals themselves would have ensured such separation during our experiments in 1983. Mid-course navigational corrections were to be made during experimental approach only to ensure a close approach and only as necessary to adjust for "undisturbed" net movements of whales due, for example, to currents (Figure 3). It would be important not to alter the operation of the airgun array or the course of the vessel if avoidance behavior were observed, as doing so would cause variation in methodology which could confound data analysis. Thus, if bowheads had avoided a vessel by increasing separation distance, no effort would have been made to change vessel heading or operation of the airgun array with the intent of reducing the separation distance or degree of acoustic stimulation. Similarly, if bowheads did not attempt or were not able to evade the oncoming vessel, changes in the vessel's course and its operational status would have been made only to avoid collisions with whales and to maintain 1 km or more of separation from the subject whales.

It would be useful to know if animals of distinct physiologic or reproductive classes react differently to a given stimulus. Therefore, all possible classes were to be included in the experiments. The most readily recognized classes are the calf and its accompanying adult, presumably the mother. In some instances, subadults can be distinguished from adults on the basis of relative size.

To reduce the possibility of interfering with the mother-calf bond, it was intended policy not to perform experiments on groups consisting **only** of mothers and calves. If such pairs were included in any test group of bowheads, the experiment would be aborted whenever a mother-calf pair appeared incapable of or failed to demonstrate an avoidance response demonstrated by other animals.

Procedures for Collecting Behavioral Data - N655MA and N642

Collection of behavioral data was the primary task of the crew onboard the Twin Otter (N655MA) and the secondary task, after monitoring geophysical vessels, of the crew on the Grumman Goose (N642). Although groups of bowheads in close proximity to geophysical vessels were preferred subjects, this situation rarely occurred in September. Instead, behavioral observations during 1983 were primarily of undisturbed migrating whales that appeared to offer the best chance for gathering consistent and reliable data. Observations from both aircraft were carried out at an altitude of 457 m (1500') or greater (Fraker et al. 1982), in order to minimize possible disturbance effects from the aircraft, and in areas where sea state was less than a Beaufort 3 and low clouds and fog were absent.

When ice was present in the area under observation, ice floes or ice-free leads were used as reference points above which to circle while whales were below the surface. When ice was not present in the immediate area, bags of fluorescein dye or Navy smoke bombs, Model Mark 1 Mod O, were dropped. These offered the best reference point for circling under all weather conditions. Sonobuoys were also dropped from the aircraft to monitor and record industrial noises, such as seismic shots, and whale sounds. Data recording techniques and gear are described in "Field Procedures for N642 and N655MA".

Behavioral observations provided data in 15 categories:

1. location of sighting (and therefore water depth, distance from shore and distance from industrial activity),
2. time of day, in Alaska Daylight Time (ADT), which is GMT minus nine hours,
3. number of individuals visible in area and number of calves,
4. individually distinguishing features, if any, on whales,
5. headings and reorientations of each whale, in degrees magnetic (changed to degrees true during analysis),
6. distances between individuals (estimated in whale lengths),

7. duration of time at surface and, for recognizable whales, duration of dives,
8. timing and number of respirations, or blows,
9. mouth open or closed,
10. possible bottom feeding as indicated by mud streaming from the mouth,
11. distance from ice and ice cover,
12. socializing, as indicated by whales interacting in close proximity,
13. aerial activity: breaches, tail slaps, flipper slaps, lunges, rolls,
14. type of dive: fluke out or fluke not out,
15. determination of other types of behavior besides 10 and 12 above: milling, traveling and possible water-column feeding.

Additionally, rate of movement estimates were collected from whales circled during behavioral observations. To collect specific information on rates of movement, only those whales with some kind of distinguishing characteristic (marks, scars, or coloration) that allowed reidentification were selected. The position (latitude °N and longitude °W, taken from the aircraft's GNS) and time (ADT) of an individual whale sighting were recorded. When the same whale was resighted, the position and time were again noted. These positions were plotted. The distance between positions, in kilometers, divided by the differential in time between the first position and the second position, gave an estimated rate of movement in kilometers per hour (km/h).

<u>Analysis Procedures for Behavioral Data - N655MA and N642</u>

Behavioral observations were transcribed from audiotape onto data recording sheets during evenings or periods of poor weather between observation flights or in the laboratory. Information on position of whales and aircraft altitude was taken from the computerized record of the flight track. Some behavioral sequences were videotaped, and the videotaped record was compared to the audiotape commentary. After the field season, transcribed observations were converted into a standardized numerical format with individual records of surfacing, respiration, and dive characteristics of each whale that was under detailed observation. These records were checked by a different individual than the one who converted them into standardized format, and were then entered into a Hewlett-Packard 85 desk-top computer. The computer record was checked after compilation and transferred to a Hewlett-Packard 9825 computer for tabulation of data and statistical analyses. A Hewlett-Packard 9825 computer with Hewlett-Packard 9827A plotter drew the numerically-based figures.

Basic parametric and nonparametric statistical tests were employed as appropriate, and are referred to in the sections in which they appear. All statistical tests used may be found in Zar (1974) or Sokal and Rohlf (1981).

Whales were assumed to be undisturbed when 1) the flight was at or above 457 m altitude, 2) there was no moving vessel within 5.0 km of the whales, and 3) no underwater industrial activity noise could be heard via sonobuoys monitored in the aircraft. Geophysical sounds were the only potential source of disturbance considered during behavioral observations described in this report. Numerical behavioral data gathered during periods when whales were subjected to geophysical sounds were classified as potentially disturbed and are presented separately from potentially undisturbed behavioral statistics.

Because calves of the year are smaller than other whales (one-third to one-half the size of the nearest adult), their surfacing, respiration, and dive characteristics were treated separately from the non-calf data which form the bulk of the data base. A non-calf whale beside a calf of the year was assumed to be the mother of that calf.

RESULTS

Ice Conditions

Ice was a major feature in the subject portion of the Beaufort Sea throughout the entire study period. In August, an east-west corridor of open water about 13 km wide extended from Harrison Bay to Barter Island (Figure 4). East of Barter Island the corridor varied in width but was usually wider than 13 km. Directly north of this open-water strip, 3/10 to 9/10 broken floe ice persisted. In early September, the open-water corridor almost disappeared as northerly winds pushed the ice toward shore. Closely-packed, broken floe ice (9/10 coverage) was present from Harrison Bay to Herschel Island and north to 71°N, where there was more open water and average coverage was 5/10 to 7/10 (Figures 5, 6). Throughout September, the ice shifted with currents and wind; however, the nearshore strip of open water was rarely wider than 15-20 km. By September 23, grease ice had begun to form in most offshore cracks and leads north of the barrier islands (Figure 7). Between September 23 and 30, the nearshore open-water corridor widened due to variations in temperature, wind speed and direction (Figure 8). Open water occurred primarily after the seismic companies had terminated their season.

Geophysical Vessel Activity, Fall 1983

Information on seismic research activity in the Alaskan Beaufort Sea during fall 1983 was provided by the MMS. Ten permits for high-energy offshore seismic work were issued in 1983, which is equivalent to the permitted activity in 1982. Eight geophysical vessels operated in the Alaskan Beaufort Sea in 1983. One vessel, the Arctic Fox, operated by Energy Analysts Exploration 48, Inc., completed its work before the monitoring program began. The remaining seven vessels were operational from August through September. Some specifications for these seven vessels are given in Table 4.

Ice interfered greatly with the operations of the geophysical vessels, leaving them little open water in which to operate. Often two or more vessels were forced to operate close to one another, alternating periods of shooting; called "time-sharing" by industry. In August and early September, all but one of the vessels (the Krystal Sea) moved incrementally farther east in search of adequate open water (Table 2). By September 6, all of the geophysical vessels except the Krystal Sea were positioned well inside Canadian waters. The E. O. Vetter managed to return to Alaskan waters west of 141° by September 8, but the other

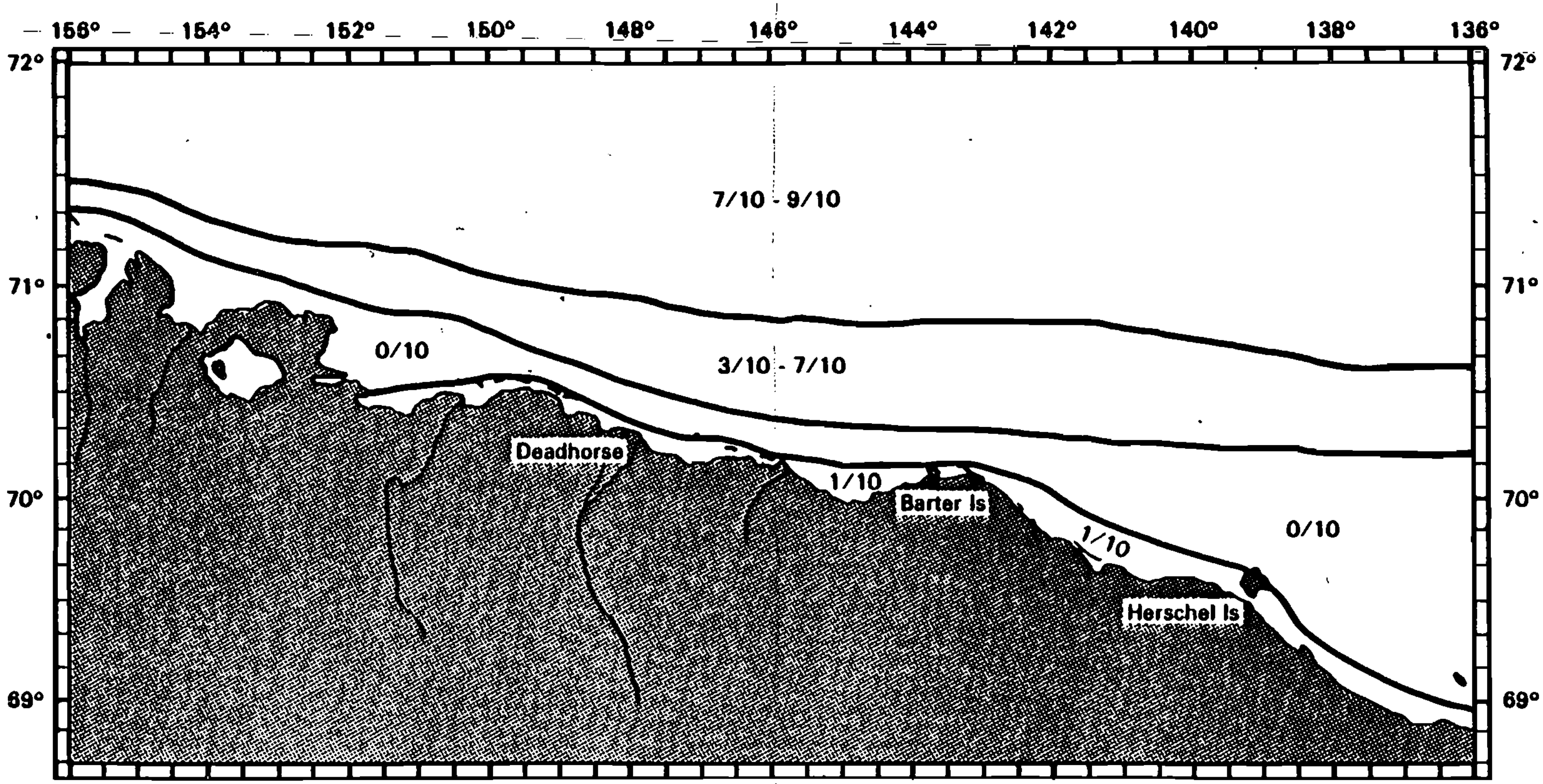


Figure 4. Schematic presentation of Beaufort Sea ice conditions, August 20, 1983.

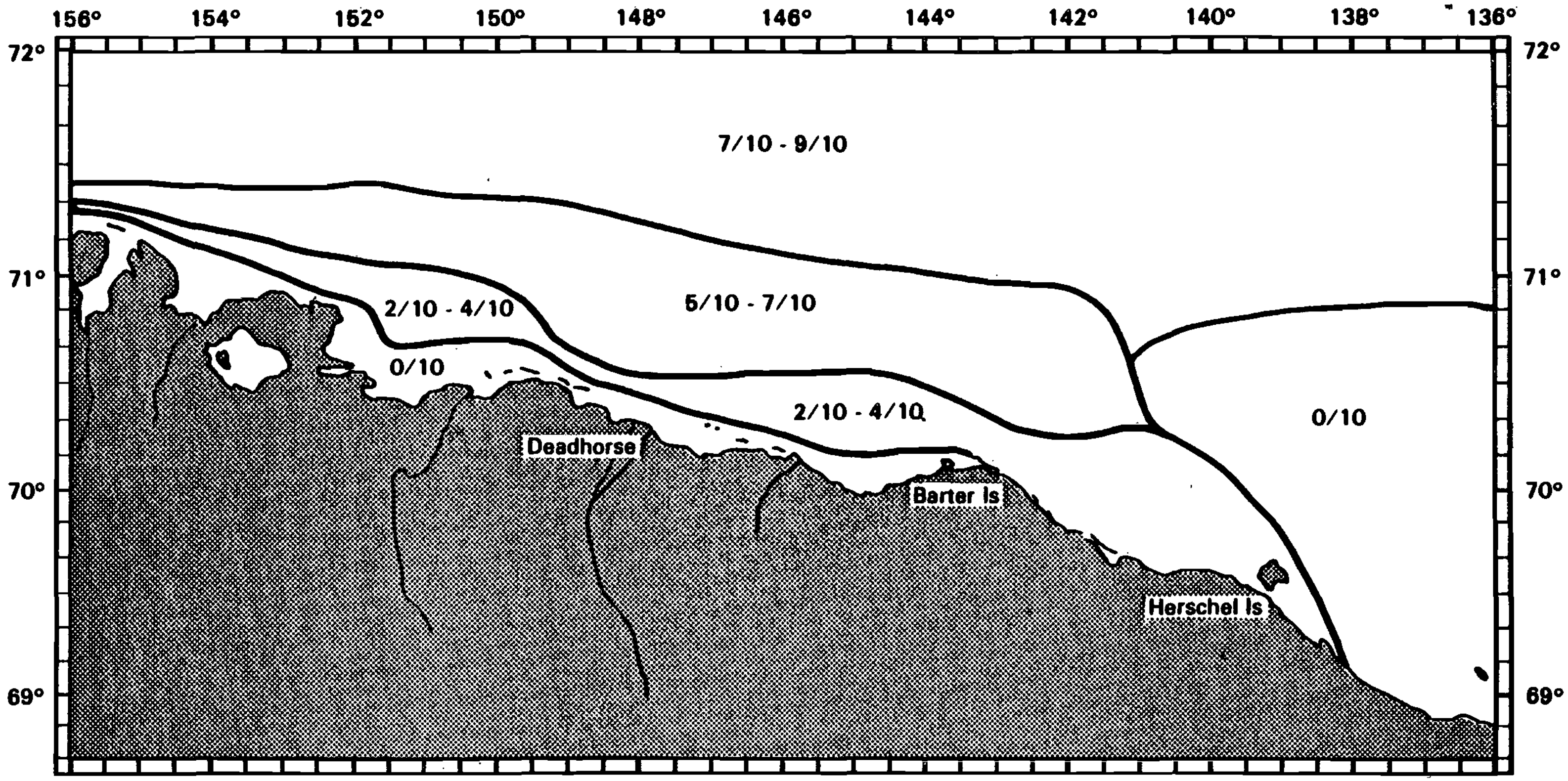


Figure 5. Schematic presentation of Beaufort Sea ice conditions, August 31, 1983.

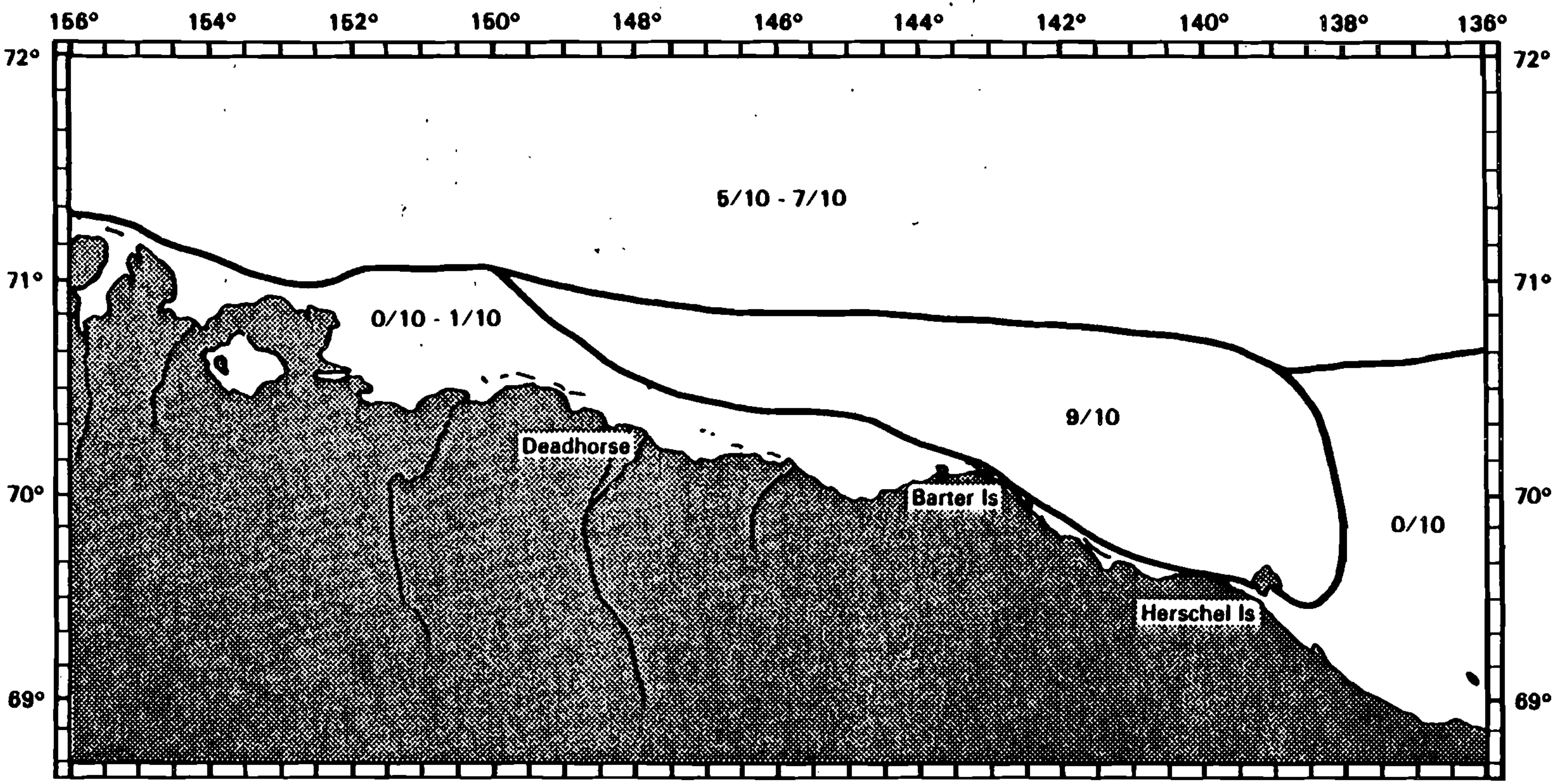


Figure 6. Schematic presentation of Beaufort Sea ice conditions, September 10, 1983.

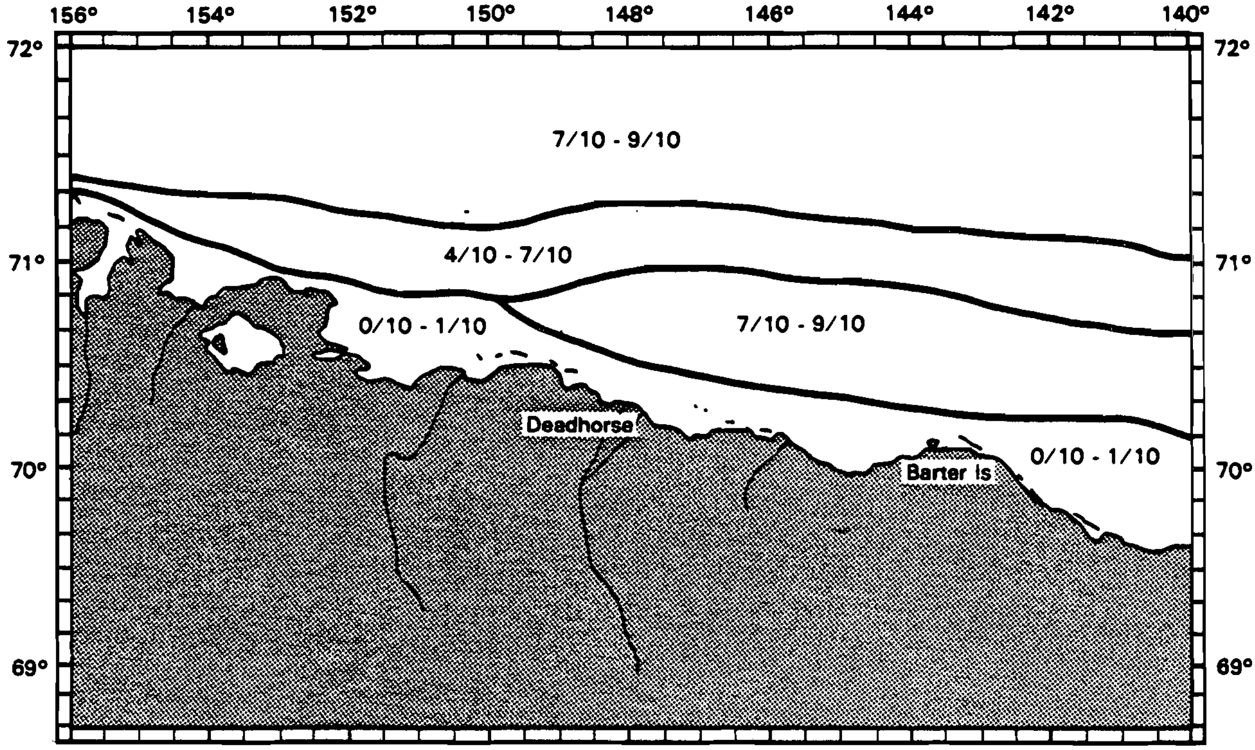


Figure 7. Schematic presentation of Beaufort Sea ice conditions, September 20, 1983.

five vessels remained in Canada, unable to return to Alaskan waters because of heavy ice which had blown against the coast between Barter Island and the Alaska-Canada border. Only one of them, the GSI Mariner, was shooting in the Canadian Beaufort (Table 2); the other four vessels were inactive. These four vessels were blocked by ice until September 14, when an ice-breaking barge, the Arctic Kiggiak, led three of them through the >9/10 ice and back into Alaskan waters (Figure 9).

Open-water seismic research in the Alaskan Beaufort Sea ended for the 1983 season on September 23, when one vessel, the GSI Mariner, was in Canada; another, the E. O. Vetter, was blocked by ice near Pt. Barrow; and the remaining five vessels were at West Dock, Prudhoe Bay. Three of the vessels remained on-call while in dock until the end of September, in the chance that winds and warmer temperatures would open up the survey areas and allow them to resume operations. By September 30, however, ice conditions had not greatly improved (Figure 10), all vessels officially closed down for the season, and our study was terminated.

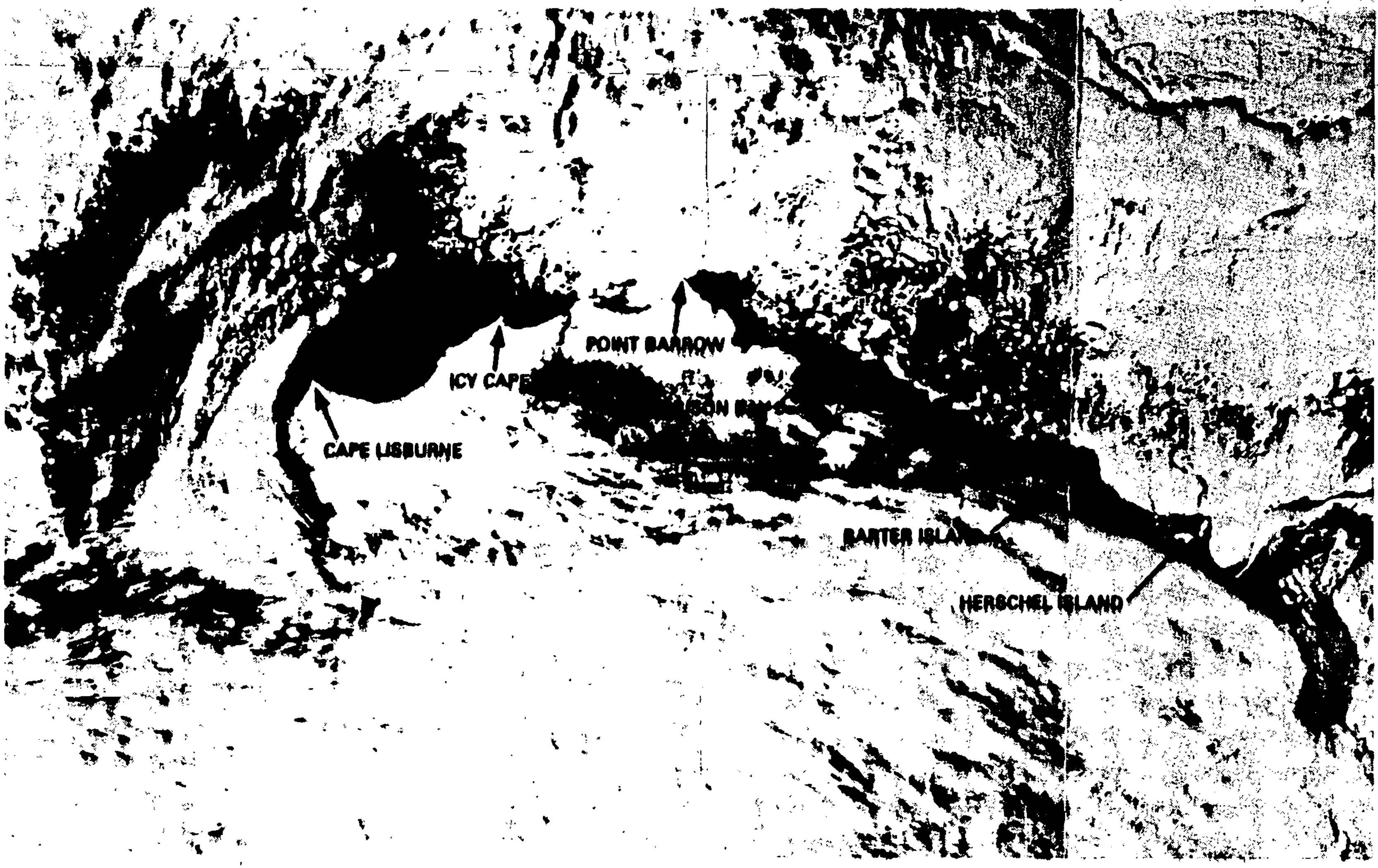


Figure 8. Satellite photo showing Beaufort and Chukchi Sea ice conditions, September 29, 1983.

Table 4. Characteristics of seismic survey vessels working in the western Beaufort Sea, August 18 to September 23, 1983.

Vessel Name	Beam (ft)	Length (ft)	Type of Engines	Horsepower Rating	Screw	Type of Sound Device	Source Level of Device [1]	Maximum Speed of Vessel (kts)	Shooting Speed (kts)
Western Polaris	32	150	12V149 Det. Diesel	1350	Twin	Airgun array	30 bar meters [2] = 250 dB	10	4.5
Arctic Star	30	100	16V71 Det. Diesel	980	Twin	Airgun array	20 bar meters [2] = 246 dB	9	4.5
Western Aleutian	32	150	12V149 Det. Diesel	1350	Twin	Airgun array	30 bar meters [2] = 250 dB	10	4.5
Krystal Sea	40	135	Two Diesel Cats	850 each	Twin	Airgun array	1190 cu. in. of air or 22 bar meters [3] = 247 dB	11	3.5-4.5
GSI Mariner	30	119	Two Diesel Cats 343	700 each	Twin	Airgun array	1410 cu. in. of air or 24 bar meters [3] = 248 dB	7	4.7
GSI Alaskan	38	188	Twin Diesel	475 each	Twin	Airgun array	4075 cu. in. of air [4]	10	5.5
E. O. Vetter	39	185	Twin Diesel	2000 each	Twin	Airgun array	4075 cu. in. of air [4]	13.5	5.5

[1] Sound pressure levels are converted from bar meters (i.e. bars at 1 m) to dB re 1 micropascal at 1 m.

[2] Provided by Western Geophysical Co. personnel in Deadhorse, September 1982.

[3] Provided by Murray Roth, Geophysical Service Inc., October 26, 1982.

[4] Provided by Larry Bowles, Geophysical Service Inc., January 26, 1984.

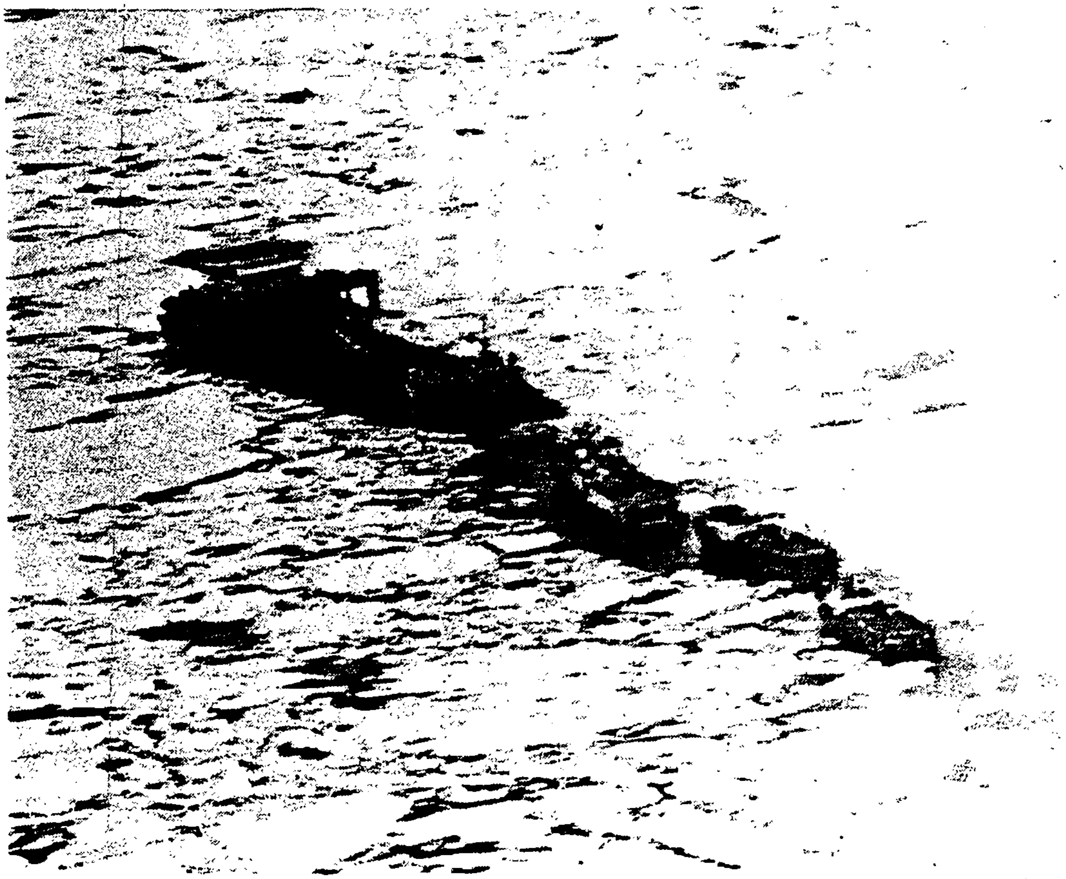


Figure 9. Canadian ice-breaking barge, Arctic Kiggiak, leading three geophysical vessels through 9/10 ice, September 12, 1983.

The amount of seismic data collected (expressed as "line miles shot") in a given year is proprietary information. However, it can be stated that, while the total mileage of proposed program lines in 1983 was almost identical to that in 1982 (within 2%), the actual mileage shot in 1983 was approximately 70% less than that in 1982. This substantial reduction in geophysical activity was due mainly to the difficult ice conditions that prevailed in 1983.

Monitoring - N642

From August 17 to September 30, the monitoring aircraft, N642, initiated 41 survey flights (Appendix A), the mean duration of which was 3 h 38 min (range: 1 h 50 min to 6 h 23 min) (Table 5). Twenty-two grids were begun near geophysical vessels; 19 of these were completed. Because vessel movements were severely limited by ice conditions, often more than one vessel was covered by the transect grid.

Prior to September 3, eight of 12 monitoring grids were flown completely or partially in Canadian waters. This concentration of effort in the eastern extreme and east of the study area was because only one vessel, the Krystal Sea, was

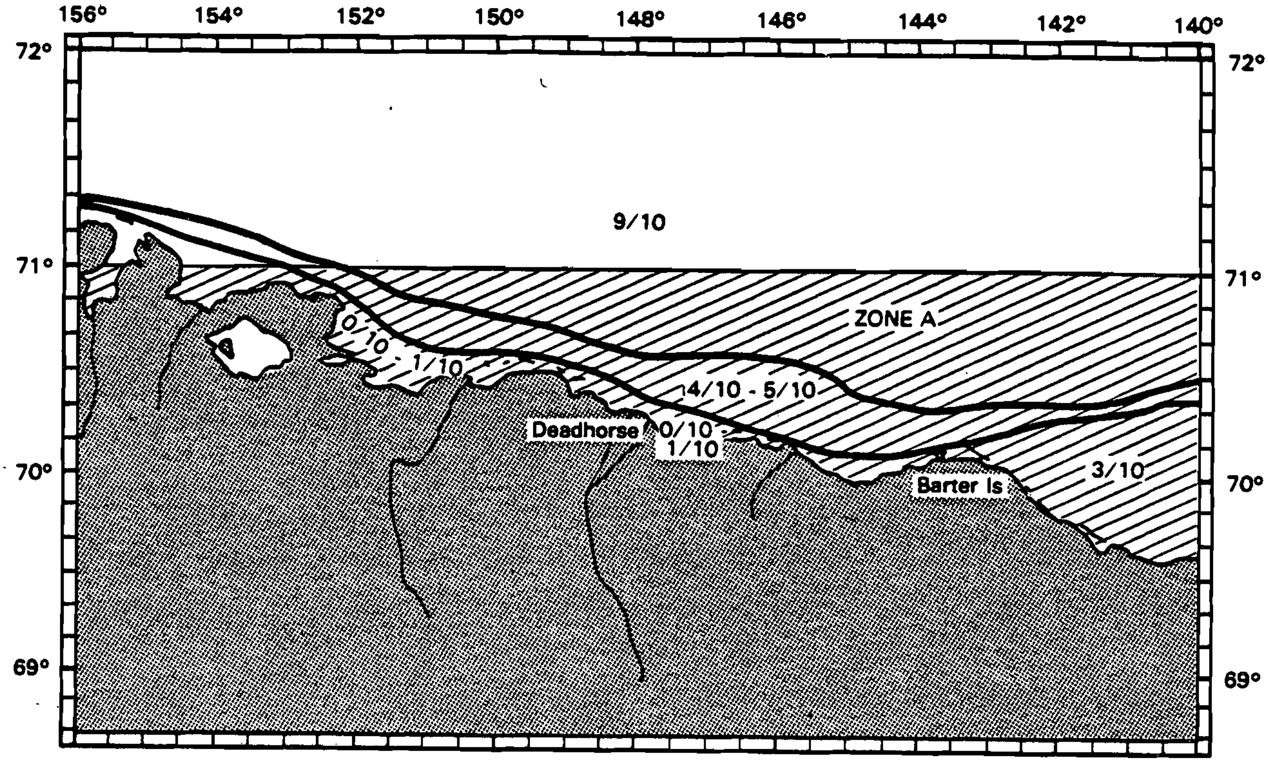


Figure 10. Schematic presentation of Beaufort Sea ice conditions, September 30, 1983. Zone A was the study area primarily used by N642 and N655MA.

operating exclusively in the Alaskan Beaufort Sea during this time and, on the basis of previous experience, it was assumed that the probability of encountering bowheads near vessels early in the monitoring season was greater in the east than in the west. Whenever the Krystal Sea was unable to work because of mechanical problems, ice conditions or inclement weather, our only choice was to make flights to the east. During the period September 5 to 14, all but two vessels were stranded in Canadian waters, and the monitoring effort centered on the Krystal Sea, which was working primarily in Harrison Bay, and the E. O. Vetter, which was working close to the coast east of Deadhorse.

After the majority of seismic vessels returned to the Alaskan Beaufort Sea on September 14, close and regular monitoring flights were carried out. However, because vessel activities were greatly limited by ice conditions, relatively little time was required to complete the grids. Search surveys to collect behavioral data, and transect surveys in support of the N780 studies were also flown, especially during the latter part of September.

Bowhead whales were sighted on 19 flights by the crew of aircraft N642 (Appendix A), accounting for approximately 19.25 h of behavioral observations (Table 5). Six sightings of 15 animals were made during grid surveys near geophysical vessels (Table 6). The majority of sightings were made north of the vessels' positions. The closest sighting of a whale to an active seismic vessel was 21.8 km on September 2 (Table 6).

The first bowhead sighting by N642 was made on August 31 in 5/10 ice coverage east of Barter Island (70°36.4'N, 142°41.7'W). The final sightings were made on September 30 north of Prudhoe and Harrison Bays during a search survey (Appendix A).

Regional surveys by the crew aboard N780 continued until October 19. Bowheads were seen in the Beaufort Sea by that crew on October 2 at 70°30.8'N, 145°20.9'W (1 whale), on October 4 northeast of Barrow (7 whales), on October 8 at 71°16.1'N, 152°19.8'W (1 whale), and on October 12 at 71°33.4'N, 156°15.5'W (1 whale). A flight on October 18 by N780 showed that the ice east of Barrow was nearly solid. Thus, it is assumed that the fall migration of bowheads through the Beaufort Sea had ended on or about October 18 (Ljungblad et al. 1984).

Thirty-nine sonobuoys were dropped during the monitoring effort (Table 7). Water depths at the points where sonobuoys were dropped ranged from about 9 m to 730 m. Airgun pulses, bowhead and belukha sounds, and ambient water noise were recorded.

<u>Seismic/Behavior Studies - N655MA</u>

This study began on August 27 and continued through September 28. The aircraft (N655MA) and crew were based primarily at Deadhorse, Alaska and the main flight effort (80 h) concentrated on the limited open water areas nearshore (Zone A, Figure 10). However, from September 7 to September 12 the base of operations was moved temporarily to Inuvik, Northwest Territory, Canada to take advantage of the opportunity to conduct experiments in open water near operating seismic vessels and bowhead whales. While at Inuvik, flight effort was directed to open water areas near Herschel Island and Mackenzie Bay (Zone B, Figure 11).

Due to heavy-ice coverage, operating seismic vessels and whales were rarely together to afford opportunities for experiments. However, on September 6 a group of feeding whales was located near 69°50'N, 136°20'W by the monitoring crew aboard N642. Seismic vessels in the area were in a standby

Table 5. Summary of flights made by N642 in August - September 1983.

Date	Flt. No.	No. of Grids Begun	Vessels Surveyed	No. of Grids Compl.	Total Hours of Behavioral Circling (hrs:min)	Total Flt. Hours (hrs:min)	Comments
18 Aug	1	2	Mariner, W. Aleutian	1	-	5:08	Five lines of second grid completed.
19 Aug	2	1	Mariner	1	-	4:00	
20 Aug	3	1	W. Polaris	1	-	4:03	
21 Aug	4	1	Mariner	1	-	4:05	
22 Aug	-	-	-	-	-	-	No flight due to bad weather.
23 Aug	5	-	-	-	-	2:28	Search.
24 Aug	6	1	E.O. Vetter	1	-	3:50	
25 Aug	7	1	E.O. Vetter	0	-	2:54	Five lines of grid completed; two flights.
26 Aug	8	1	Arctic Star	1	-	4:15	
27 Aug	-	-	-	-	-	-	No flight due to aircraft mechanical problems.
28 Aug	-	-	-	-	-	-	No flight due to aircraft mechanical problems.
29 Aug	9	1	Krystal Sea	1	-	2:17	
30 Aug	10	-	-	-	-	1:50	Aborted flight due to bad weather.
31 Aug	11	1	Alaskan	1	:07	4:08	
1 Sept	-	-	-	-	-	-	No flight due to bad weather.
2 Sept	12	1	Aleutian	1	:05	4:48	Two flights.
3 Sept	13	1	E.O. Vetter	0	:20	6:23	Five lines of grid completed; three flights.
4 Sept	14	-	-	-	-	4:29	Search; two flights.
5 Sept	15	1	Krystal Sea	1	-	1:55	
6 Sept	16	-	-	-	:57	5:46	Search; three flights.
7 Sept	17	-	-	-	-	2:10	Search.
8 Sept	18	1	Krystal Sea	1	1:00	3:30	
9 Sept	19	-	-	-	-	4:00	Block 4; two flights.
10 Sept	20	-	-	-	-	2:35	Block 1; eastern half.
10 Sept	21	1	Krystal Sea	1	-	3:43	Block 1; western half.
11 Sept	-	-	-	-	-	-	No flight due to bad weather.
12 Sept	22	1	E.O. Vetter	1	-	2:31	
12 Sept	23	-	-	-	2:17	4:31	Search.
13 Sept	-	-	-	-	-	-	No flight due to aircraft maintenance.
14 Sept	24	1	W. Aleutian	1	-	2:49	
15 Sept	25	1	W. Polaris	1	-	2:46	
15 Sept	26	1	Alaskan, W. Aleutian	1	:15	3:02	
16 Sept	27	1	Krystal Sea	1	1:30	3:38	
17 Sept	-	-	-	-	-	-	No flight due to bad weather.
18 Sept	28	1	Alaskan, W. Aleutian	1	-	2:49	Two additional lines of grid flown.
18 Sept	29	-	-	-	1:15	4:11	Search.
19 Sept	-	-	-	-	-	-	No flight due to bad weather.
20 Sept	-	-	-	-	-	-	No flight due to bad weather.
21 Sept	30	1	Krystal Sea	1	1:00	4:00	
22 Sept	31	-	-	-	-	2:20	Search; navigation computer not functioning.
23 Sept	32	-	-	-	-	2:40	Block 4.
24 Sept	-	-	-	-	-	-	No flight due to bad weather.
25 Sept	33	-	-	-	:05	3:59	Block 3.
26 Sept	34	-	-	-	1:20	5:38	Block 5; two flights.
27 Sept	35	-	-	-	1:42	3:18	Block 4; western half.
27 Sept	36	-	-	-	:15	2:53	Block 4; eastern half.
28 Sept	37	-	-	-	:05	3:15	Block 1.
28 Sept	38	-	-	-	2:11	4:06	Search.
29 Sept	39	-	-	-	2:25	3:42	Search.
29 Sept	40	-	-	-	2:00	2:52	Search.
30 Sept	41	-	-	-	:25	6:07	Search; two flights.
TOTAL		22		19	19:14	149:24	

Table 6. Bowhead sightings on 2,000 km^2 monitoring grid around geophysical vessels, Beaufort Sea, Fall 1983.

Date	Flt. No.	BOWHEADS Position	Time Of Sighting (ADT)	No.	Hdg. (°M)	VESSEL BEING SURVEYED Name	Position	Time (ADT)	Hdg. (°M)[1]	Speed (Kts)[2]	Vessel Status[3]	Estimated Distance Bowheads To Vessel (Km)	Direction Bowheads From Vessel	Comments
Sept 2	12	70°10.3'N 139°37.6'W	1122	1	120	Western Aleutian	70°00.2'N 139°51.9'W	1058	210	4.5	Active	21.8	NE	3 other vessels in area.
Sept 3	13	69°24.8'N 137°24.4'W	1459	1	270	Edward O. Vetter	69°35.0'N 138°03.9'W	1418	130	4.5	Active	26.5	SE	1 other vessel in area.
Sept 3	13	69 °05.8'N 137°25.9'W	1502	1	300	Edward O. Vetter	69°35.0'N 138°03.9'W	1418	130	4.5	Active	26.5	SE	1 other vessel in area.
Sept 8	18	70°58.9'N 150°08.4'W	1339	1	300	Krystal Sea	70°47.6'N 150°02.1'W	1256	270	-	Inactive	41.6	NE	Barges, cranes, industrial activity at Mukluk Island.[4]
Sept 15	26	70°23.9'N 145°06.3'W	1616	1	240	Western Aleutian	70°15.6'N 145°55.9'W	1522	120	4.5	Active	34.2	NE	2 other vessels in area.
Sept 16	27	70°55.7'N 149°49.0'W	1432	10	270	Krystal Sea	70°45.0'N 151°14.2'W	1327	130	4.5	Active	57.0	NE	

[1] At time vessel was sighted at beginning of grid; may have changed during period of grid survey.

[2] Assumed to remain constant.

[3] At time of whale sighting.

[4] An artificial island under construction in Harrison Bay at 70°40'N, 150°55'W.

Table 7. Locations and recorded subjects of sonobuoy drops (N642).

Date	Flt #	Sonobuoy Type[1]	Position Latitude (N)	Position Longitude (W)	Working Yes/No	Subject Recorded
8/18	1	-	70°21.9'	140°35.9'	No	-
8/19	2	57A	-	-	No	-
8/20	3	57A	70°14.8'	140°43.5'	Yes	3 seismic vessels
8/21	4	41A	70°06.0'	139°04.0'	Yes	Seismic vessel
8/29	9	57A	70°50.9'	151°10.2'	No	-
8/31	11	57A Mod	69°56.7'	139°24.4'	No	-
8/31	11	41A	70°03.4'	139°43.0'	Yes	2 seismic vessels
9/2	12	57A Mod	69°59.2'	139°44.9'	Yes	-
9/3	13	57A Mod	70°35.6'	150°24.6'	No	-
9/3	13	57A Mod	70°35.9'	150°24.3'	No	-
9/3	13	57A Mod	69°35.1'	138°04.8'	Yes	-
9/3	13	57A	69°41.3'	138°13.4'	Yes	Seismic vessel
9/3	13	57A Mod	69°42.6'	137°48.0'	Yes	-
9/3	13	57A	69°25.1'	137°24.4'	Yes	Seismic vessel, bowhead
9/4	14	57A	69°50.6'	137°36.3'	Yes	Faint seismic vessel
9/5	15	57A	70°55.0'	151°15.4'	Yes	Seismic vessel
9/6	16	57A	69°49.8'	136°20.2'	No	-
9/6	16	57A	69°52.0'	136°21.0'	No	-
9/8	18	57A	70°58.2'	150°11.2'	No	-
9/10	20	-	70°27.5'	147°16.8'	No	-
9/10	21	57A	70°52.1'	150°55.9'	Yes	Seismic vessel
9/12	23	57A	70°58.0'	144°18.0'	Yes	Bowhead, belukha
9/15	25	57A	70°11.7'	145°07.5'	Yes	Seismic vessel
9/15	26	57A	70°18.8'	145°42.7'	No	-
9/16	27	57A	70°53.8'	151°13.5'	No	-
9/16	27	57A Mod	70°51.6'	151°21.1'	Yes	-
9/18	28	57A	70°28.7'	147°23.1'	Yes	Seismic vessel
9/18	28	57A	70°21.4'	145°44.5'	Yes	Ambient noise
9/18	29	57A	70°24.4'	140°55.6'	Yes	Bowhead, belukha
9/21	30	57A	70°47.9'	151°32.4'	No	Hit ice
9/21	30	57A	70°45.9'	151°40.4'	Yes	Seismic vessel
9/21	30	57A	71°10.4'	148°47.1'	Yes	Belukha, aircraft
9/26	34	-	70°03.9'	142°43.6'	No	-
9/27	35	57A	70°27.8'	144°59.3'	Yes	Ambient noise
9/28	38	57A	71°10.2'	149°44.9'	Yes	Ambient noise
9/29	39	57A	70°11.4'	143°27.2'	Yes	Ambient noise
9/30	41	-	70°27.8'	147°39.4'	No	-
9/30	41	57A	70°39.6'	147°33.7'	No	-
9/30	41	57A	70°40.6'	147°31.1'	Yes	Vessel noise
	TOTAL	39				

[1]57A Mod = a 57A sonobuoy modified to receive higher sound pressure levels.

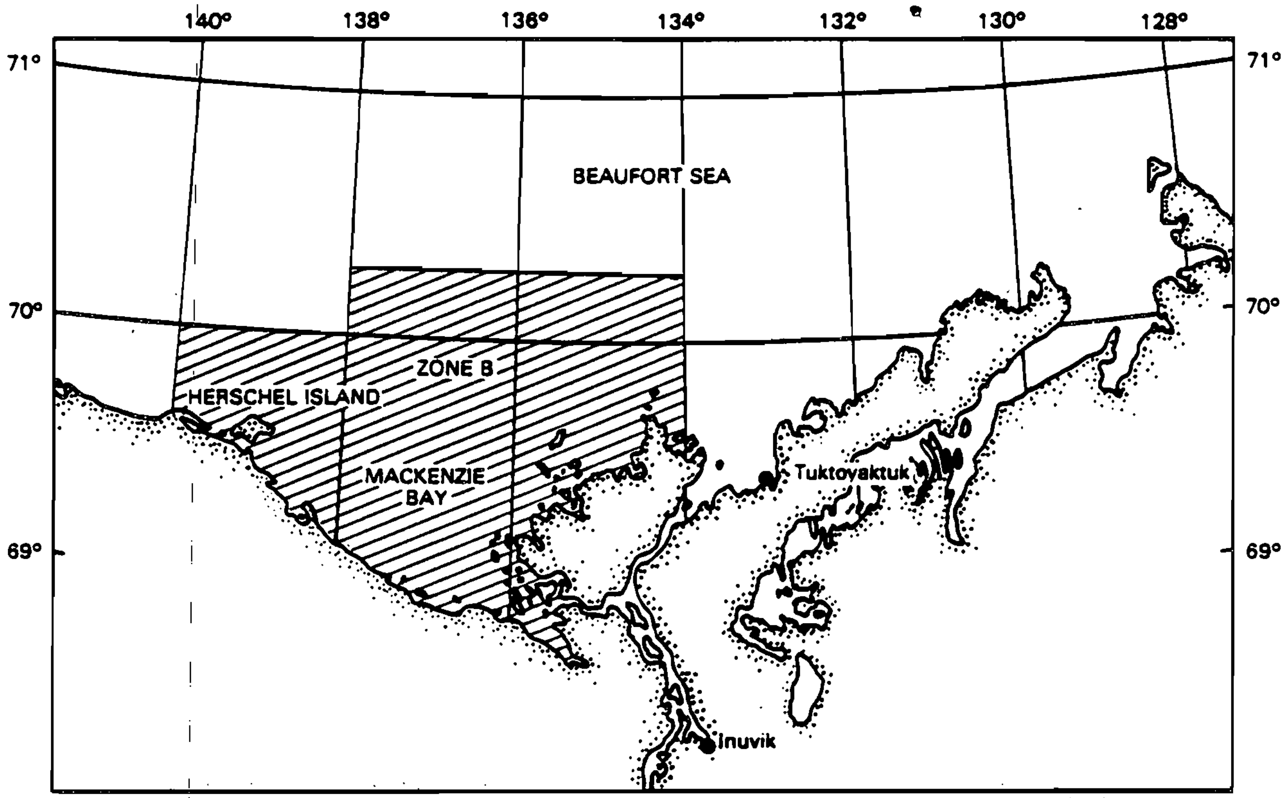


Figure 11. Study area in the eastern Beaufort Sea.

mode. On September 7 the behavioral study crew aboard N655MA proceeded to the area. The seismic vessel, Western Aleutian, located nearby, was contacted at 1215 ADT prior to the arrival of the aircraft and requested to place their airguns in the water. However, the area had been covered with 7/10 to 8/10 ice overnight and no whales were found there or in open water areas north of the position. The Western Aleutian was informed at 1436 ADT that no whales had been found and no experiment would be conducted.

Another experimental opportunity occurred on September 9. The seismic vessel Western Aleutian, located at 70°10.0'N, 134°45.0'W, reported at 0859 ADT that whales were observed from the vessel. The crew aboard N655MA arrived at 0915 ADT and found whales within 1.0 km of the vessel. However, low ceilings (<152 m) and high sea state (Beaufort 05) prevented the possibility of an experiment.

Continued low ceilings and the attempted return of most seismic vessels to Alaskan waters prompted the return of N655MA to Deadhorse, Alaska, on September 11. Flights from then until the end of the seismic season (September 24) were concentrated within the limited, open water area located nearshore in the Alaskan Beaufort Sea (Figure 10). Whales were not located near operating seismic vessels, and were usually separated by at least 40 km of 8/10 to 9/10 ice coverage. Limited data were obtained from whales traveling offshore through heavy broken floe ice, but traveling whales were usually sighted only briefly and not resighted due to heavy-ice coverage. After the end of the seismic season late in September, whales were observed on two occasions feeding nearshore near Barter Island. These whales were observed for long periods of time, and extensive data were collected. Therefore, although active traveling was the predominant behaivor observed in 1983, data were also collected on feeding whales.

The heavy-ice conditions and limited amount of open water offshore prevented seismic-behavior experiments. Geophysical vessels were usually located far south of the main migration route through the Alaskan Beaufort Sea. Most of the data were collected on unexposed whales as they traveled through heavy ice in the Alaskan Beaufort Sea.

Rate of Movement Estimates

Rate of movement estimates were calculated for five individual bowheads on four days (Table 8). The range was 2.5 to 7.2 km/h, with an average of 5.0 $\pm$ s.d. 1.97 km/h, n=5. Four animals for which a rate was calculated were adults (one was considered a subadult) and three were breaching at some time during the observation period. Ice coverage was generally 3/10 to 9/10 and sea state was Beaufort 0 to 1.

Four of the whales were resighted only once. However, the adult bowhead observed on September 8 was resighted four times, resulting in four separate rate of movement estimates for one individual, ranging from 3.1 to 9.5 km/h, with an overall net rate of 4.0 km/h and an average rate of 6.8$\pm$ s.d. 3.13, n=4.

The two whales for which estimates were calculated on September 12 were both sighted and recorded while in a large open-water lead (see Appendix A, Flight 23), and both displayed breaching and swimming sequences during the period of observations.

The whale sighted on September 18 breached initially and continued to display at the surface until a sonobuoy was dropped nearby. It dove and resurfaced nearby.

On September 26, a distinctively marked bowhead was sighted within a group of six to seven possibly feeding whales at the start of a transect leg. Three

Table 8. **Rate of movement estimates for individual bowhead whales in the Alaskan Beaufort Sea, fall 1983.**

Whale No.		1	2	3	4	5
Date		Sept 8	Sept 12	Sept 12	Sept 18	Sept 26
Initial Sighting	Position (Lat N, Long W)	70°58.5 150°08.4	70°57.6 144°17.7	70°59.5 144°19.0	70°24.1 140°57.5	70°02.0 142°32.0
	Time (ADT)	1339	1551	1629	1520	1033
1st Resight	Position (Lat N, Long W)	70°58.4 150°12.8	71°00.7 144°18.2	71°00.1 144°19.5	70°25.7 140°54.8	70°04.0 142°43.4
	Time (ADT)	1428	1627	1639	1542	1344
	Rate of Movement (km/h)	3.1	6.8	4.5	7.2	2.5
2nd Resight	Position (Lat N, Long W)	70°59.6 150°14.8				
	Time (ADT)	1456				
	Rate of Movement (km/h)	5.2				
3rd Resight	Position (Lat N, Long W)	71°00.3 150°14.5				
	Time (ADT)	1503				
	Rate of Movement (km/h)	9.5				
4th Resight	Position (Lat N, Long W)	71°01.8 150°14.0				
	Time (ADT)	1521				
	Rate of Movement (km/h)	9.2				
Age Class		adult	adult	subadult	adult	adult
Behavior		swimming	breaching, swimming	breaching, swimming	breaching, swimming	feeding, milling
Surface Heading (°M)		300	240	240	340	300
Ice Coverage		3/10	6/10	6/10	9/10	9/10
Sea State		1	0	0	0	0
Water Depth (m)		22	549	549	366	9
Net Movement (km)		6.8	4.1	0.9	2.9	7.9
Total Time Elapsed (h)		1.7	0.6	0.2	0.4	3.2
Estimated Net Rate of Movement (km/h)		4.0	6.8	4.5	7.2	2.5
Average Rate of Movement (km/h)		6.8 ± s.d. 3.13 n=4	-	-	-	-

Table 9. **Rate of movement estimates for "groups" of bowheads in the Alaskan Beaufort Sea, fall 1983.**

Group No.		1	2
Date		Sept 12	Sept 16
Initial Sighting	Position (Lat N, Long W)	70°58.1 144°18.3	70°53.9 149°49.8
	Time (ADT)	1522	1432
1st Resight	Position (Lat N, Long W)	71°00.7 144°31.8	70°57.0 150°02.2
	Time (ADT)	1721	1538
Approximate No. of Animals		10	10
Behavior		swimming	swimming
Surface Heading (°M)		240	270
Ice Coverage		6/10	3/10
Sea State		0	1
Water Depth (m)		915	18
Net Movement (km)		8.1	9.4
Total Time Elapsed (h)		1.9	1.1
Estimated Rate of Movement (km/h)		4.3	8.5

hours later at the end of the transect, the same whale was resighted 7.9 km from its original position, providing a rate of movement of 2.5 km/h.

Rates of movement for "groups" of whales were calculated on two occasions (Table 9). The positions taken at both initial sighting and at resighting were positions central to the entire group. Inability to positively identify most of the bowheads within these groups makes possible the chance that the animals seen in the resighting were not the same animals seen in the first sighting. Therefore, these rates are approximated at best and should be treated as such.

The first group of approximately 10 whales was sighted at about 1700 on September 12. They were heading 240° and appeared to comprise the same group seen earlier at 1522. It is assumed that at least some of these animals were resights and an estimated rate of movement for the entire group of 4.3 km/h was calculated.

The second group of approximately 10 whales for which a rate of movement was estimated was swimming along the edge of the nearshore open-water corridor on September 16 (Appendix A, Flight 27) providing an approximate rate of movement of 8.5 km/h.

Behavioral Observations - N655MA and N642

Both aircraft, N655MA and N642, conducted flights in search of whales near geophysical vessels throughout September 1983. Flight tracks and narrative summaries for the monitoring effort (Grumman N642) are given in Appendix A. The Grumman (N642) flights ranged from 154°W to 136°W, and as far north as 222 km offshore. The Twin Otter (N655MA) flights generally ranged from Prudhoe Bay, Alaska (148°27'W) east to the Alaska-Canada border and up to approximately 80 km offshore. Combined behavioral observations leading to numerical evaluations of surface, respiration and dive characteristics were carried out on 13 days (September 6, 8, 12, 13, 15, 16, 18, 21, 26, 27, 28, 29 and 30). A summary of aerial observations of bowhead behavior is presented in Table 10.

Bowhead whales are generally thought to be traveling as they pass the north coast of Alaska in September, migrating from summer feeding grounds in the eastern Beaufort Sea and Amundsen Gulf to wintering areas near the ice edge in the Bering Sea. Yet, as Ljungblad et al. (1983) have pointed out, much feeding and some socializing also takes place in Alaskan waters during September. In September 1983, the ice remained in the nearshore area and bowheads were not seen nearshore until the end of the month. Therefore, most behavioral observations were made on small groups of whales traveling through broken ice more than 30 km from shore. Apparent bottom feeding, indicated by whales surfacing with mud streaming from their mouths, was observed on September 6 in Canadian waters (at 69°49'N, 136°21'W); possible feeding in the water column, indicated by whales milling in an area, diving for relatively long periods of time, and surfacing briefly, occurred on August 31, September 2, 16, 18, 26 and 29. Socializing, as evidenced by two or more whales interacting in close physical proximity, was noted sporadically throughout the month, and seemed to occur less in September than during the preceding month in the Canadian Beaufort Sea (Würsig et al. 1984). Aerial activity including breaches, tail slaps and flipper slaps were also observed sporadically and infrequently, although perhaps more frequently than in fall 1982 (Ljungblad et al. 1983; Reeves et al. 1983).

Table 10. A summary of aerial observations of bowhead behavior, 1983. An asterisk (*) denotes those observations for which numerical data was obtained. Plane 1 is the Twin Otter N655MA; Plane 2 is the Grumman Goose N642.

Date (1983)	Plane No.	Time Over Bowheads Start (ADT)	Stop (ADT)	Total Hours	Distance From Shore and Approximate Position (Latitude, Longitude)	Depth of Water (m)	Estimated Number of Whales Adults	Calves	Estimated Area Under Observation (km^2)	Disturbance	General Behavior
Aug 31	2	1455	1500	0.08	60 km northeast of Barter Island (70°36.4'N, 142°41.7'W)	457	1	0	10	None Known	Some Aerial Activity, Milling
Sept 2	2	1122	1127	0.08	61 km northwest of Herschel Island (70°10.3'N, 139°37.6'W)	254	1	0	10	Seismic[1]	Milling, Possibly Feeding
Sept 3	2	1459	1519	0.33	59 km east of Herschel Island (69°25'N, 137°25'W)	37	2	0	10	Seismic[1]	Some Aerial Activity, Slow Travel
Sept 6	2	*1226	1250	0.40	104 km north of Barter Island (70°59'N, 143°34'W)	1280	2	0	10	None Known	Milling, Socializing
	2	*1453	1507	0.25	93 km east northeast of Herschel Island (69°49'N, 136°20'W)	16	4	1	15	Small Vessel; Industrial Island	Feeding
Sept 8	2	*1428	1528	1.00	81 km east northeast of Cape Halkett (70°58'N, 150°13'W)	22	1	0	10	Seismic Assumed	Medium Speed Travel
Sept 9	1	0920	1114	1.90	102 km northwest of Tuktoyaktuk (70°10'N, 134°43'W)	35	7	1	15	None Known	Milling
Sept 12	1	*1225	1307	0.70	83 km northeast of Barter Island (70°30'N, 141°58'W)	92	3	1	15	None Known	Slow to Medium Speed Travel
	2	*1519	1736	2.28	98-107 km northeast of Barter Island (70°58'N, 144°20'W)	549-915	10	2	30	None Known	Aerial Activity, Travel
Sept 13	1	*1202	1313	1.18	86 km northeast of Barter Island (70°31'N, 141°42'W)	183	1	1	10	None Known	Slow Travel
Sept 15	1	*1149	1204	0.25	23 km north of Demarcation Bay (69°54'N, 141°09'W)	40	1	0	10	None Known	No forward motion
	1	*1237	1239	0.03	59 km northeast of Demarcation Bay (70°11'N, 140°29'W)	46	1	0	10	None Known	Slow Travel
	2	*1616	1631	0.25	67 km northwest of Barter Island (70°24'N, 145°06'W)	38	1	0	10	Seismic[1]	Slow Travel
Sept 16	2	*1432	1602	1.50	81-93 km east of Cape Halkett (70°55'N, 149°50'W)	18-22	10	0	10	Seismic	Slow Travel
Sept 18	1	*1037	1129	0.87	89 km east of Cape Halkett (70°54'N, 149°45'W)	22	1	0	10	Seismic	Rapid Travel
	2	*1521	1636	1.25	105-113 km northwest of Herschel Island (70°25'N, 140°58'W)	366	4	0	10	None Known	Medium Speed Travel, Milling

Table 10 (contd).

Date (1983)	Plane No.	Time Over Bowheads Start (ADT)	Stop (ADT)	Total Hours	Distance From Shore and Approximate Position (Latitude, Longitude)	Depth of Water (m)	Estimated Number of Whales Adults	Calves	Estimated Area Under Observation (km2)	Disturbance	General Behavior
Sept 21	1	•1417	1434	0.28	53 km east of Barter Island (70°08'N, 142°09'W)	29	3	1	10	None Known	Slow Travel
	2	•1127	1227	1.00	95-100 km north of Prudhoe Bay (71°09'N, 148°40'W)	137-183	6	2	20	None Known	Medium To Rapid Travel
Sept 23	1	1405	1500	0.92	7 km northeast of Barter Island (70°12'N, 143°22'W)	10	4	0	10	None Known	Slow Travel
Sept 25	1	1315	1345	0.50	52 km northeast of Prudhoe Bay (70°45'N, 147°24'W)	38	1	0	10	None Known	Medium to Rapid Travel
Sept 26	2	•1335	1455	1.33	37-41 km east-southeast of Barter Island (70°02'N, 142°34'W)	9	6-7	0	15	None Known	Milling, Feeding
Sept 27	1	•1136	1411	1.58	46 km northwest of Barter Island (70°32'N, 144°04'W)	46	7	0	20	None Known	Medium to Rapid Travel
	1	•1604	1646	0.70	53 km northwest of Barter Island (70°30'N, 144°35'W)	42	6	0	20	None Known	Medium to Rapid Travel
	2	•1018	1200	1.70	50-55 km northwest of Barter Island (70°27'N, 144°52'W)	42	7-10	0	20	None Known	Slow to Rapid Travel
Sept 28	1	•1207	1702	5.08	51 km northeast of Barter Island (70°11'N, 143°23'W)	13	10	0	30	None Known	Water Column Feeding
	2	•1436	1647	2.18	92-107 km northwest of Prudhoe Bay (71°09'N, 149°44'W)	62-183	7	2	30	None Known	Travel
Sept 29	2	•0951	1216	2.42	7 km east of Barter Island (70°11'N, 143°24'W)	11	8-10	0	10	None Known	Milling, Feeding
	2	•1435	1635	2.00	1 km north of Flaxman Island (70°14'N, 146°09'W)	7	10	0	10	None Known	Milling, Feeding
Sept 30	2	•1548	1555	0.12	75 km east-northeast of Cape Halkett (71°04'N, 150°15'W)	18	2	0	10	None Known	Medium to Rapid Travel

[1]Observations made in the presence of these seismic sounds are not included in disturbance data since no usable data on surfacing, respiration or dive characteristics were obtained.

Respiration, Surfacing and Dive Characteristics

The four major quantitative characteristics which have been used to describe the dive profile of bowhead whales are 1) interval between blows (respirations), 2) number of blows per surfacing, 3) length of time at the surface (surface time), and 4) length of time below the surface (dive time) (Würsig et al. 1983). The first three characteristics can be ascertained while watching individual whales which are not reidentifiable, but the fourth, dive time, requires that a whale be recognizable by some distinguishing feature or features, such as the extent of the white chin patch, or presence of scars or other white or tan marks on the back or tail. The interval between blows is the only characteristic which does not require observation of a full surfacing, consequently it was the most frequently collected datum. Dive times, on the other hand, since they require that the preceding moment of diving and the subsequent moment of surfacing be known, were gathered less frequently. Overall, the following data were obtained in 1983: 1,404 blow intervals, 177 number of blows per surfacing, 195 surface times and 73 dive times. However, these data include values from calves of the year and from whales potentially disturbed by industrial seismic activity. The quantitative data on undisturbed non-calves consists of 1,261 blow intervals, 154 number of blows per surfacing, 168 surface times and 59 dive times, with those for potentially disturbed whales numbering 143, 23, 27, and 14 respectively (Table 11).

Because respiration, surfacing and dive characteristics may differ according to the nature of a whale's activity or behavior, they can sometimes be used to interpret the type of activity in which whales are engaged. It has also been found that these characteristics may change with disturbance (Reeves et al. 1983; Richardson et al. in press), so data gathered under undisturbed conditions are a prerequisite for interpretation of potential responses to disturbance and these data follow.

Figures 12 a-d present the frequency distributions of the four main respiration characteristics. While blow interval, number of blows per surfacing, and the length of surfacing showed distributions approaching normality, length of dive was less normally distributed. Therefore, the first three variables have been compared by parametric testing procedures throughout this report, while the fourth variable has been treated non-parametrically. Intervals between blows of undisturbed non-calf bowhead whales averaged 14.4 ± s.d. 9.46s, n = 1,261. Number of blows per surfacing averaged 5.6 ± s.d. 3.34, n = 154; and length of

Table 11. Summary statistics for the principal surfacing, respiration and dive variables, fall 1983. All categories except those labelled otherwise are for presumably undisturbed non-calves.[1]

Category	Blow Interval (s)			Number of Blows per Surfacing			Length of Surfacing (min)			Length of Dive (min)		
	$\bar{x}$	s.d.	n	$\bar{x}$	s.d.	n	$\bar{x}$	s.d.	n	$\bar{x}$	s.d.	n
All non-calves, disturbed	27.6	40.70	39	3.7	1.56	12	1.50	1.246	15	9.24	5.342	6
All non-calves, undisturbed	14.4	9.46	1261	5.6	3.34	154	1.33	1.095	168	7.11	5.943	59
Time of day												
10-12	13.3	6.46	270	6.9	2.78	26	1.41	0.608	30	11.99	4.979	9
12-14	15.1	9.46	462	5.8	3.47	48	1.31	0.880	52	6.66	5.365	23
14-16	12.7	6.90	312	5.5	3.89	38	1.24	0.898	41	7.65	7.145	15
16-18	16.1	8.23	217	4.6	2.67	42	1.16	0.813	45	3.66	3.512	12
Depth of water (m)												
<30	12.0	11.35	631	5.4	3.24	81	1.04	0.626	88	9.08	6.664	27
30-59	17.7	13.59	304	5.5	3.03	35	1.42	0.866	35	4.84	4.861	14
60-89	16.2	9.00	98	3.7	2.38	15	1.21	0.743	16	5.62	5.276	4
>90	17.0	12.34	223	7.4	3.91	23	1.84	1.031	29	6.02	4.807	14
Class of whale												
calf	15.0	14.69	104	8.5	4.25	11	2.10	1.077	12	8.57	4.127	8
mother (=cow)	17.6	6.49	87	7.2	4.38	11	2.11	1.022	11	8.63	4.256	8
other non-calf	14.0	8.22	1174	5.4	3.20	143	1.21	0.777	157	6.87	6.164	51
Associations												
alone	13.4	8.05	935	5.5	3.20	110	1.32	0.743	111	6.13	5.383	33
1-5 lengths	16.1	7.20	111	5.4	3.13	14	1.57	0.921	17	10.12	6.075	7
>1 length	17.2	8.34	215	5.5	3.86	34	1.40	1.090	34	7.71	6.664	19
General behavior												
travel	16.7	9.15	611	5.5	3.12	73	1.48	0.870	75	6.01	5.187	31
column feeding	11.7	6.23	582	5.4	3.26	75	1.01	0.616	82	8.78	6.602	26

1Sample sizes in individual categories do not always equal total number (n) for undistrubed non-calves; it was not possible to determine depth, class, association or behavior for every whale.

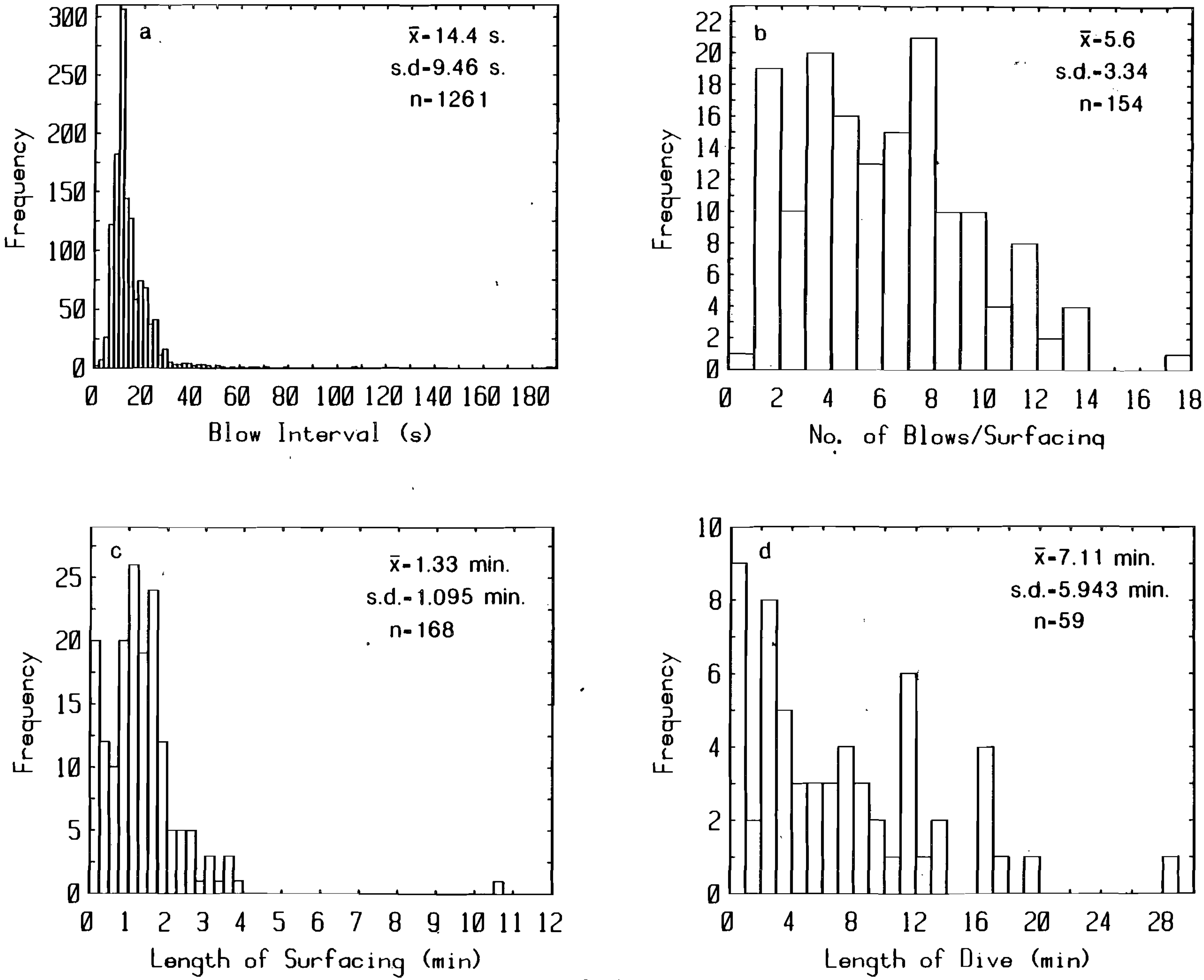


Figure 12. Frequency distributions of the respiration, surfacing and dive characteristics for presumably undisturbed non-calves.

surfacings averaged 1.33 ± s.d. 1.095 min, n = 168. The average length of dives was 7.11 ± s.d. 5.943 min, n = 59.

Figures 13 a-d present the mean value of each of the four characteristics during each day with data. Although there appear to be large fluctuations between some days, we could discern no consistent day to day pattern which might be attributed to seasonal factors. Some of the observed variations between days may be attributed to differences in overall general activities of whales encountered on different days, while some of the differences may be spurious and unrepresentative due to small sample sizes. We address differences due to different activities in later sections of this report.

Numbers of blows per surfacing and length of surfacing were highly positively correlated (Figure 14), as has been consistently found for bowheads in summer (Würsig et al. in press). However, length of one dive (previous dive) compared to length of the next dive (subsequent dive) was not correlated (Figure 14), and this lack of correlation is dramatically different from the highly correlated times in series of dives by bowheads in summer (Würsig et al. 1983). This lack of correlation in September 1983 may be related to the heavy ice that covered potential feeding areas in the Alaskan Beaufort Sea during 1983. The heavy ice may also have partially dictated the surfacings of whales since open water areas were limited.

Time of Day

Data were gathered from 1000 to 1800 Alaska Daylight Time (ADT). The day was divided into four equal two-hour segments for statistical comparisons of respiration, surfacing, and dive characteristics (Figures 15 a-d). Blow intervals showed no clearly consistent trend, although the lows of 1000-1200 and 1400-1600 were significantly lower than the highs of 1200-1400 and 1600-1800 (ANOVA, $F = 10.504$, Error df = 1.257, $p<0.001$; Student-Newman-Keuls Test, SNK, $p<0.05$ for equality of these times, all other time comparisons not significantly different). Number of blows per surfacing decreased as the day advanced, and the 1600-1800 value was significantly lower than the 1000-1200 value (ANOVA, $F = 2.922$, Error df = 150, $p = 0.0360$; SNK $p<0.05$). Length of surfacing and length of dive showed no discernible relationship with time of day (ANOVA, $F = 0.248$, Error df = 173, $p = 0.8625$; and Kruskal-Wallis, $H = 4.246$, df = 3, $p = 0.2361$, respectively).

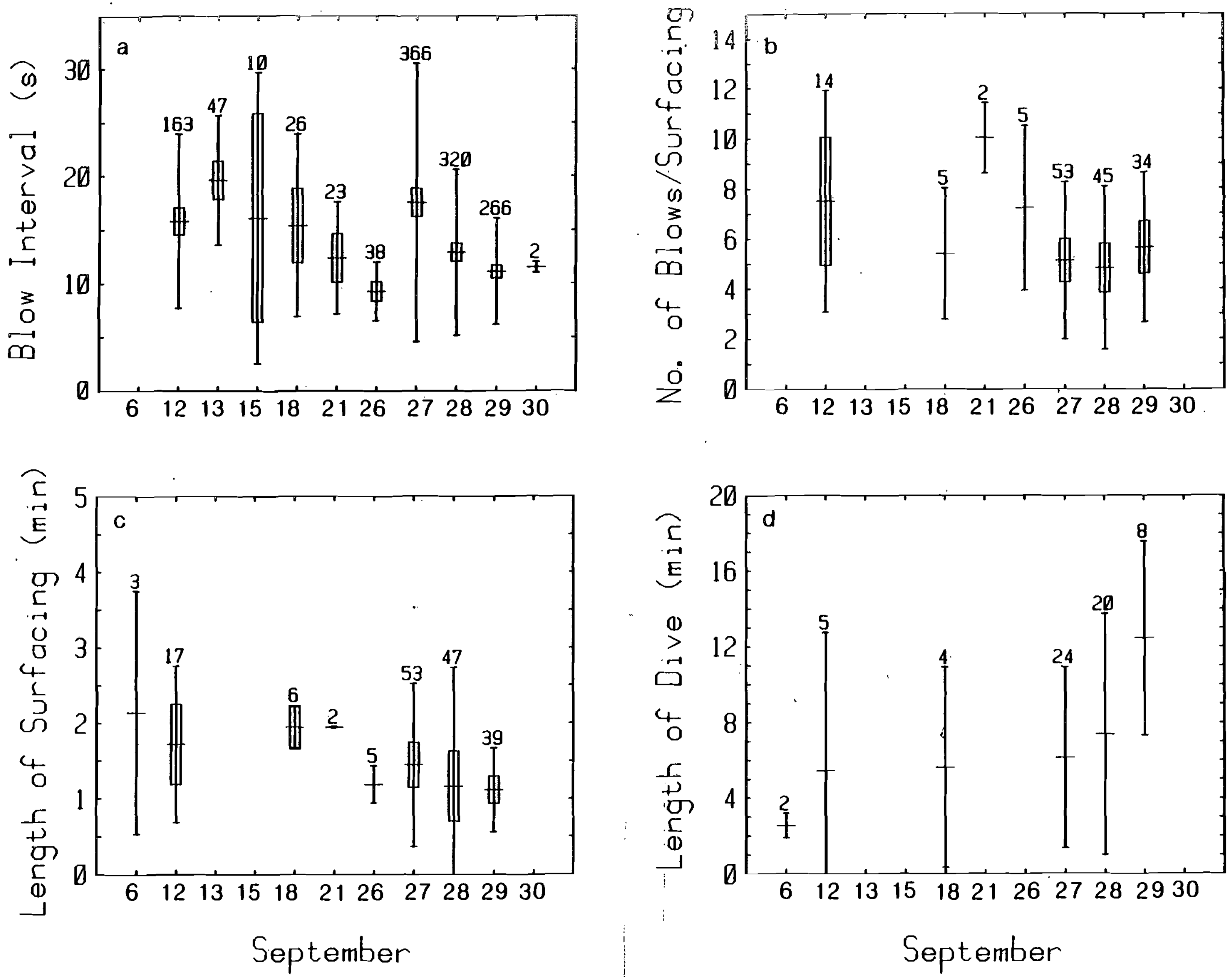
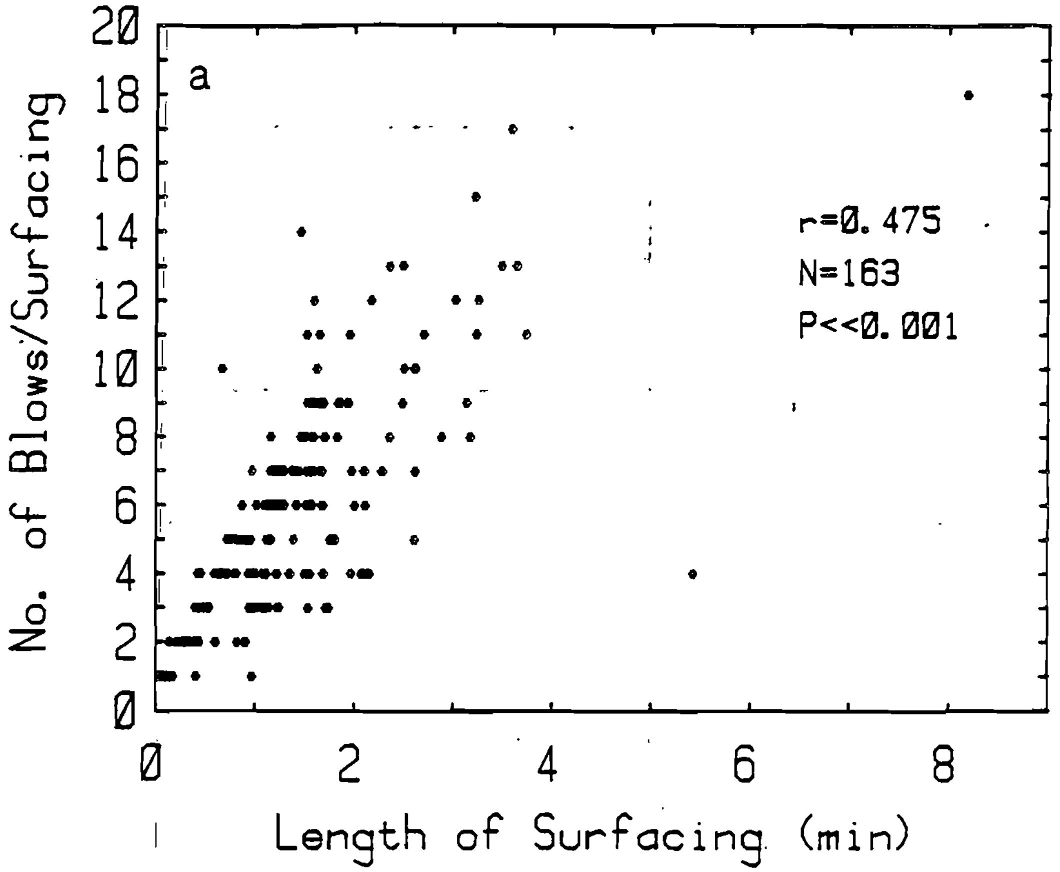


Figure 13. Respiration, surfacing and dive characteristics for presumably undisturbed non-calves per date in September. The vertical line in each column represents one standard deviation on either side of the mean, the box represents the 95% confidence interval for the mean, and the number at the top of the line is the sample size. Confidence intervals are not shown for means calculated from ≤5 data points, nor for length of dive because of the non parametric nature of this distribution.



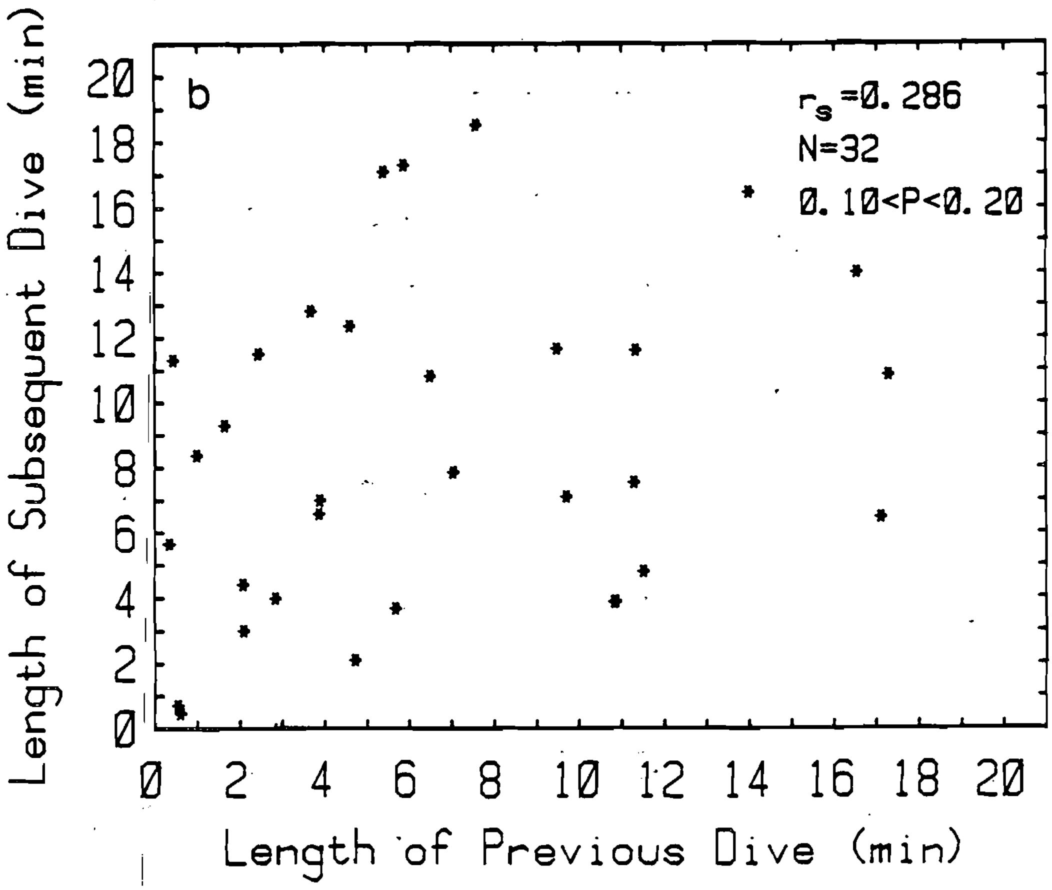


Figure 14. Correlations of several of the respiration, surfacing and dive characteristics for presumably undisturbed non-calves. r_s is the Spearman rank correlation coefficient.

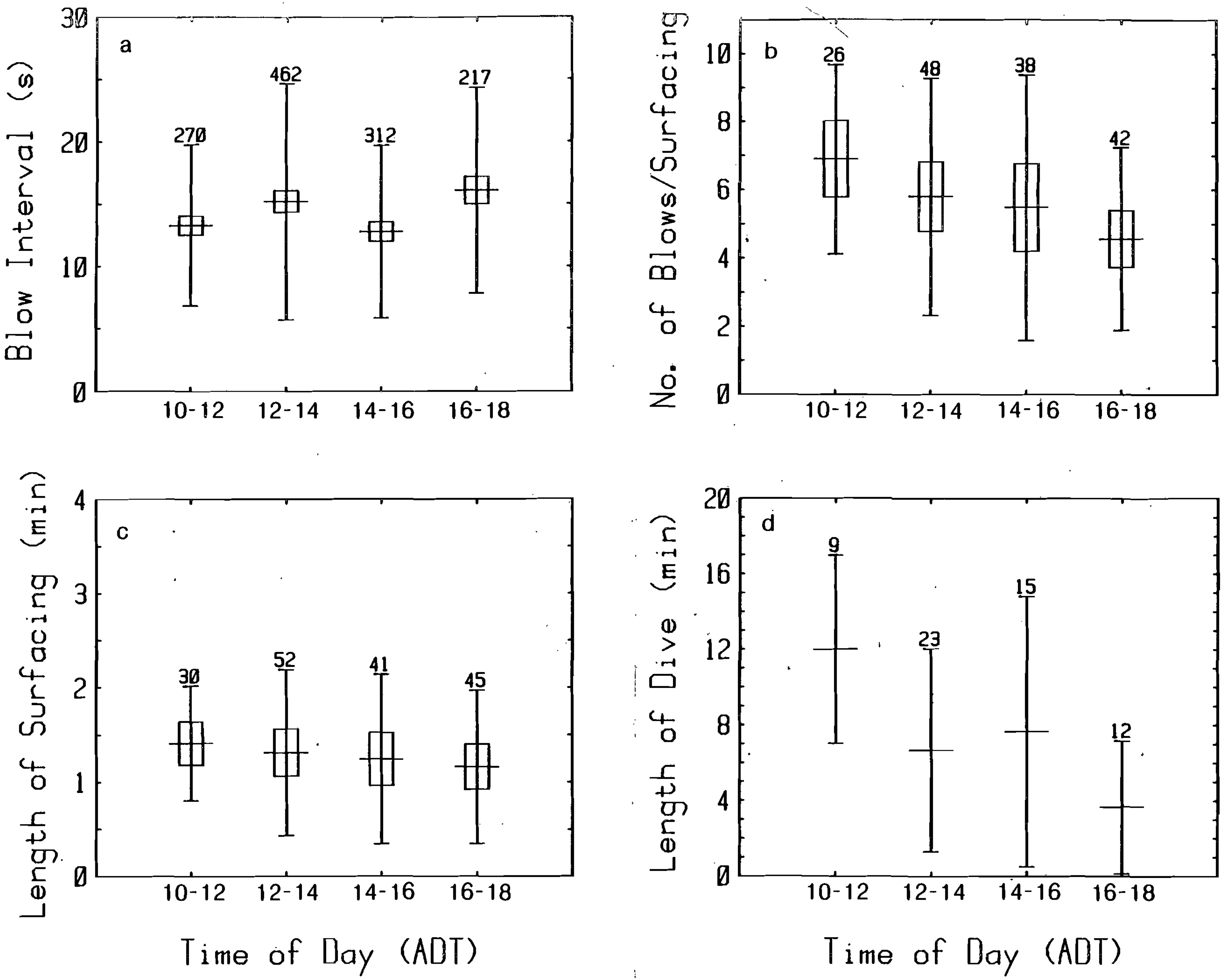


Figure 15. Respiration, surfacing and dive characteristics by two-hour time of day intervals for presumably undisturbed non-calves. Presentation as in Fig. 13.

Depth of Water

Whales were observed in depths of water ranging from 7 to 1,885 meters. For consistency, and to have enough data points in different depth categories for statistical comparisons, depths were divided into four categories, as presented in Figure 16 a-d. Blow intervals were shortest for the < 30 m depth category, and the intervals for this category were significantly different from those of deeper water (ANOVA, $F = 20.012$, Error df = 1252, $p = 0.001$). Number of blows per surfacing and length of surfacing both showed somewhat similar trends, with higher values in the > 90 m depth category than in the three categories of shallower water (ANOVA, $F = 4.234$, Error df = 150, $p = 0.0066$, and $F = 8.482$, Error df = 164, $p < 0.001$, respectively). No trend was apparent for length of dive, with a non-significant tendency towards slightly longer dives in the shallowest depth category. However, dive data suffer especially from low sample sizes, and the resultant non-significant tendencies may be spurious.

Class of Whales

The only classes of whale distinguishable from the air were calves of the year (approximately one-half the size of adults), large whales traveling with calves (presumed to be mothers of those calves), and other whales. This third category includes both juveniles and adults and is referred to as "other non-calves" (Figures 17 a-d). Mothers (=cows) had longer blow intervals than both calves and other non-calves (ANOVA, $F = 6.967$, Error df = 1362, $p < 0.002$). Number of blows per surfacing were not significantly different between mothers and calves, but both of these classes of whales exhibited more blows per surfacing than did other non-calves (ANOVA, $F = 6.288$, Error df = 162, $p < 0.0023$; SNK, p 0.01 for other non-calves and calves compared, and p 0.005 for other non-calves and mothers compared). Correspondingly, mothers and calves also showed longer surface times than did other non-calf whales (ANOVA, $F = 11.997$, Error df = 177, $p = 0.001$; SNK, $p<0.001$ for other non-calves and calves, and $p < 0.005$ for other non-calves and cows). Lengths of dives appeared longer for calves and mothers than for other non-calves, although the differences were not statistically significant, probably due to low sample sizes.

Association Between Whales

Because whales might be engaged in different activities or behave differently depending on whether they are with other whales or not, animals were classified into three categories of association. These are 1) lone whales (greater than five non-calf whale lengths from another whale), 2) whales within 1 to 5

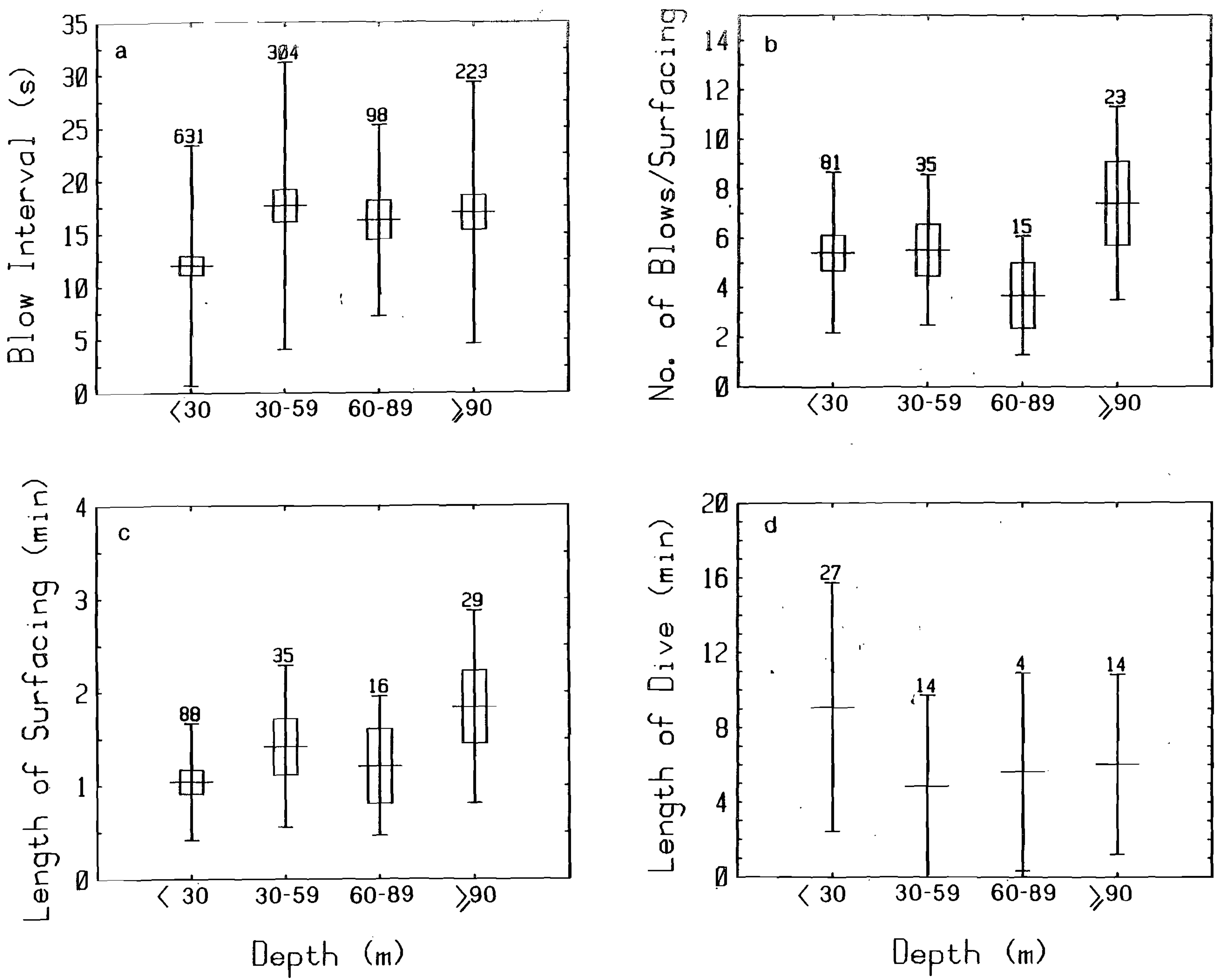


Figure 16. Respiration, surfacing and dive characteristics by four depth categories for presumably undisturbed non-calves. Presentation as in Fig. 13.

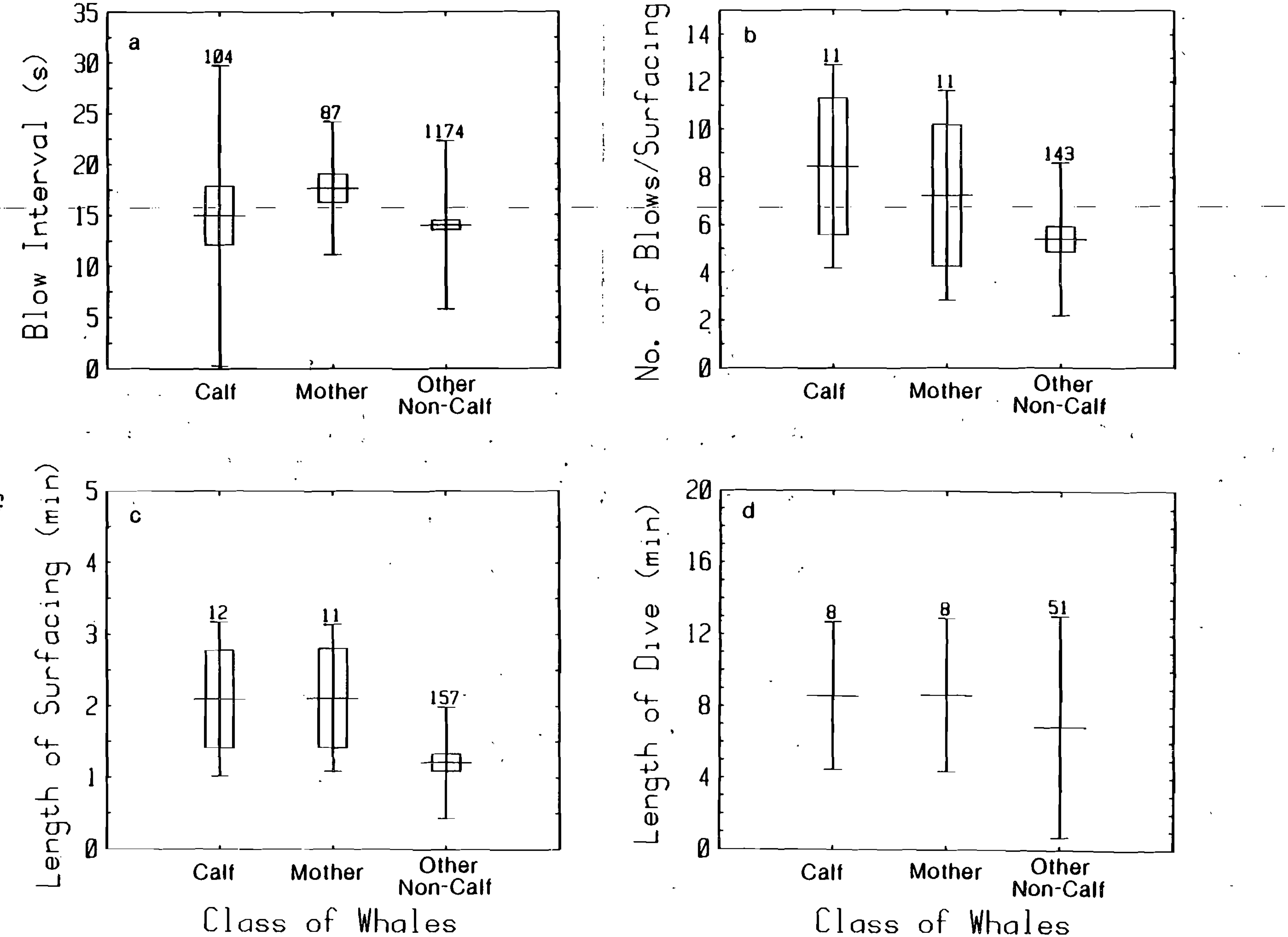


Figure 17. Comparison of respiration, surfacing and dive characteristics of calves, mothers and all other whales, for presumably undisturbed whales. Presentation as in Fig. 13.

lengths of another whale, and 3) whales within 1 length of another whale. This last category includes whales which were simply traveling close together and those which were actually interacting. Lone whales had shorter blow intervals than those within five lengths of another whale ($F = 22.305$, Error $df = 1258$, $p < 0.001$). Numbers of blows per surfacing were remarkably consistent for all three categories (Figures 18 a-d), and no statistically significant trend was observed for surface or dive times.

Categories of General Behavior

Migrating whales were most often encountered for only brief periods during September 1983, as they swam around, through or under vast ice fields. Nevertheless, to meet the objectives of the study, six types of general behavior were categorized. These are: 1) socializing (whales interacting in some manner at close proximity), 2) milling (whales oriented in different directions at the surface and with no further information on their activity), 3) bottom feeding (whales surfacing with mud streaming from their mouths), 4) suspected water-column feeding (whales diving repeatedly in an area and usually staying at the surface only briefly), 5) traveling (directed movement, with rapid passage through an area), and 6) undetermined (usually due to brief sightings). Sufficient data were gathered for comparisons of respiration, surfacing and dive characteristics for only two of these categories: suspected water-column feeding and traveling, with the latter representing the most common behavior seen (Figures 19 a-d). Whales possibly feeding in the water-column exhibited shorter intervals between blows than those judged to be traveling ($t = 10.998$, $df = 1191$, $p < 0.001$), and surface times were also significantly shorter for the possibly feeding whales ($t' = -3.8945$, $df = 155$, $p < 0.05$). Number of blows per surfacing did not differ between suspected water-column feeding and traveling whales. Dives tended to be somewhat longer for suspected water-column feeding whales than for traveling whales but, perhaps due to small sample sizes, this trend was not statistically significant. Most suspected water-column feeding occurred in shallow water (Table 10). Also, blow intervals and lengths of surfacing for all undisturbed non-calf whales were also shorter in shallow water. Thus, it is not certain whether the variable of behavior or depth was primarily responsible for the apparent differences between feeding and traveling whales. The predominance of traveling behavior may have been the main contributing factor, since Würsig et al. (in press) did not find consistent changes in respiration, surfacing and dive characteristics with depth in the eastern Beaufort Sea in

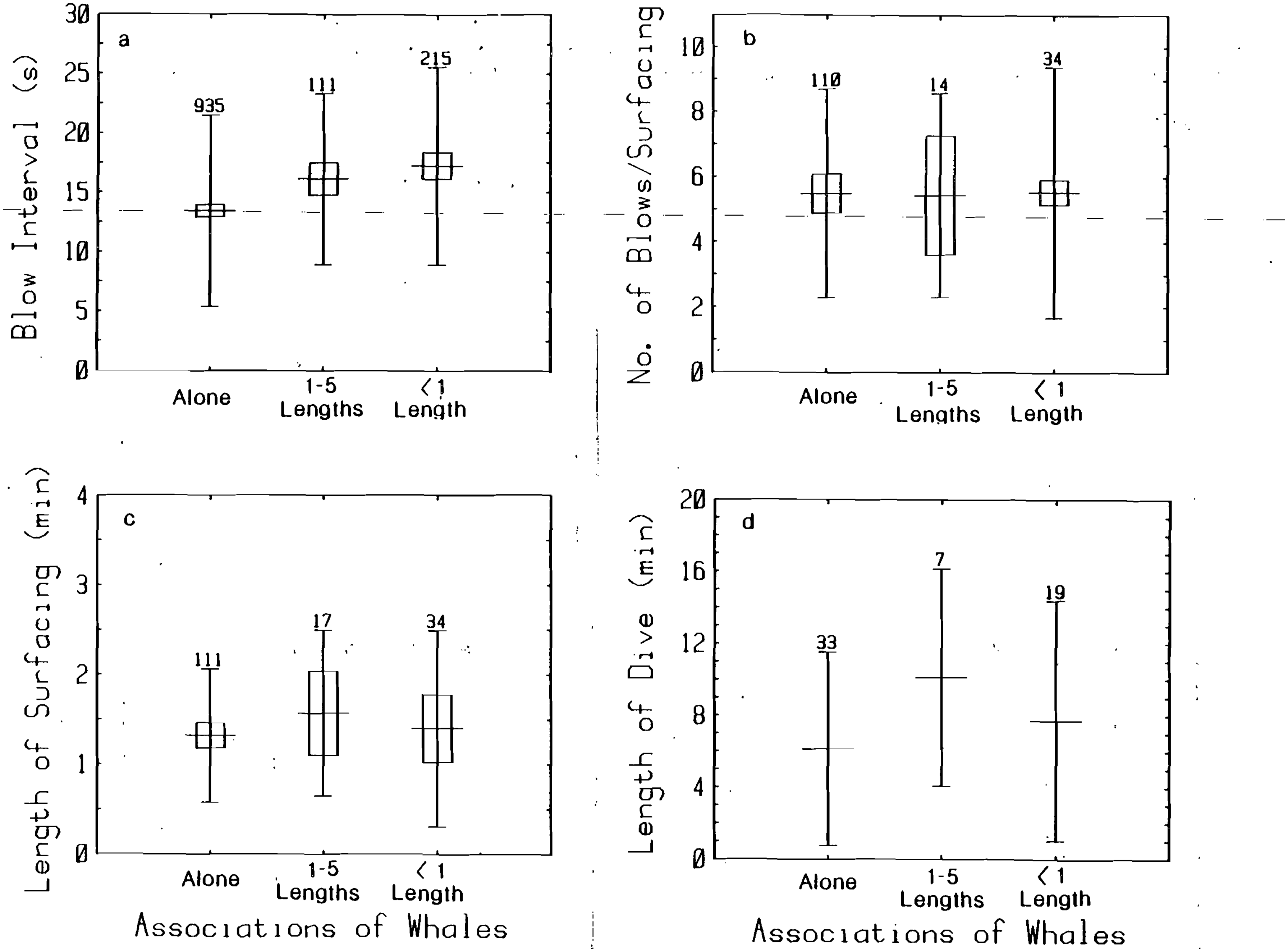


Figure 18. Respiration, surfacing and dive characteristics by whether whales are alone (separated by 5 adult whale lengths), within 1 to 5 adult whale lengths, or within 1 whale length, for presumably undisturbed non-calves. Presentation as in Fig. 13.

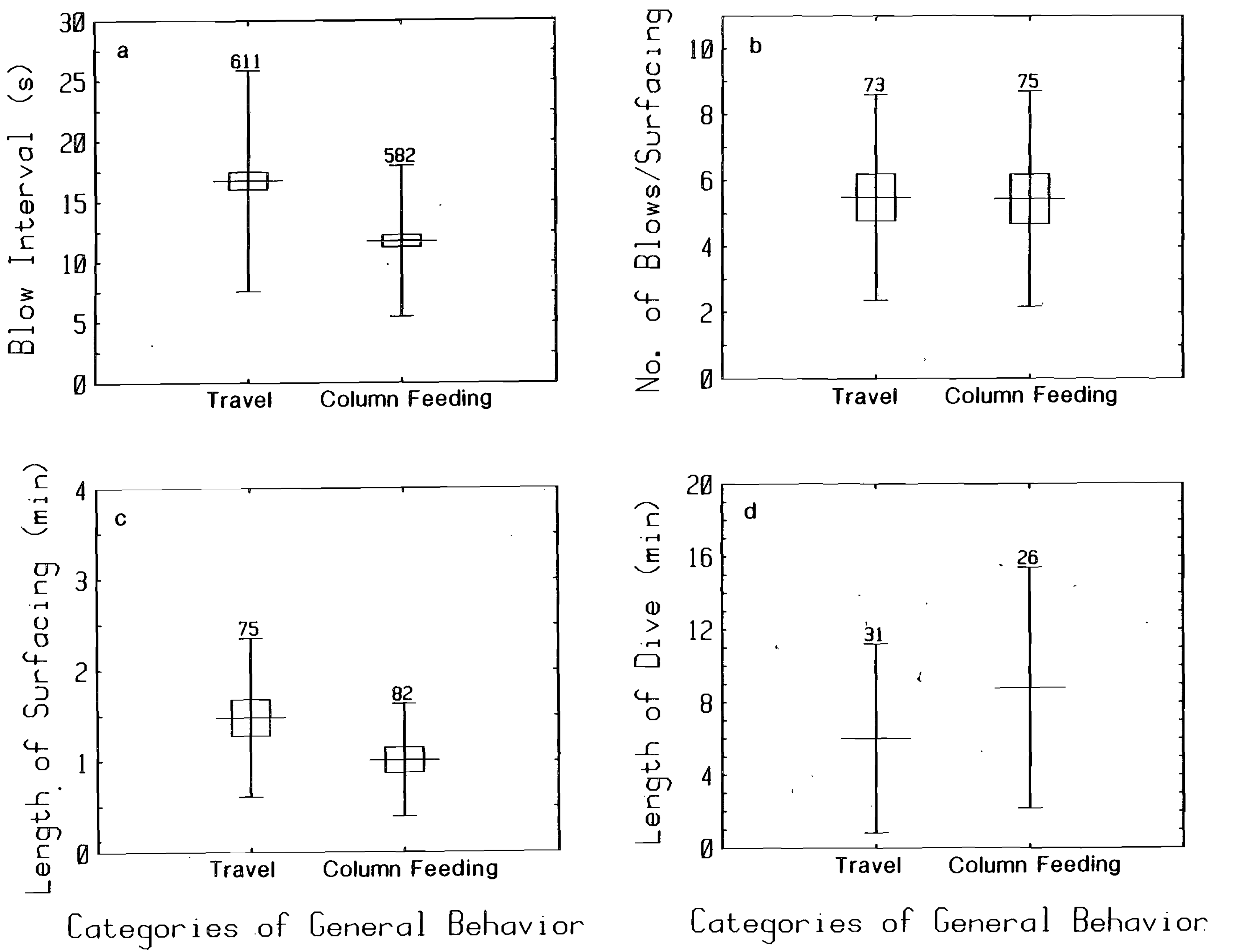


Figure 19. Respiration, surfacing and dive characteristics by behavioral categories of travel and possible feeding in the water column for presumably undisturbed non-calves. Presentation as in Fig. 13.

summer. As more data become available, clear delineation between feeding whales and traveling whales may be possible. Multivariate statistical analysis, which was sensibly not applied to our present small sample sizes, may resolve the ambiguity among potential contributing factors.

Potentially Disturbed versus Undisturbed

During most observations in the Alaskan Beaufort Sea in September 1983, whales were not near industrial activity, and thus were presumed undisturbed. During portions of flights on September 2, 3, 8, 15 and 16 (N642) and September 18 (N655MA), geophysical "shots" were heard via sonobuoys at the same time whales were under observation and these sounds were considered as potentially disturbing to the whales. Usable data on surfacing, respiration and dive characteristics were collected on September 8, 16 and 18 only, when the geophysical vessels were approximately 42, 57 and 54 km south of the whales, respectively.

Several trends were discernible between potentially disturbed and undisturbed whales (Figures 20 a - d). Blow intervals were almost but not quite significantly longer at the 0.05 level for potentially disturbed than for undisturbed whales ($t' \doteq 1.9321$, df = 1298, $0.05 < p < 0.10$). Number of blows per surfacing was significantly reduced for potentially disturbed whales ($t' = 3.6124$, df = 164, $p < 0.05$), but neither lengths of surfacing nor lengths of dive were significantly different between potentially disturbed and undisturbed categories ($p < .306$ for lengths of surfacing; $p < .230$ for lengths of dive).

Measurements of Waterborne Seismic Survey Signals, Fall 1983

Ice conditions in Fall 1983 were severe enough to curtail large scale measurements of seismic survey signals from numerous geophysical vessels. However, one vessel, the Western Polaris, was recorded in the Alaskan Beaufort Sea on September 22, 1983. The water depth was 20 m, the ranges varied from 1.62 to 11.34 km, and the source was an airgun array at depth 6 m with a reported source level of 244 dB re 1 microPascal. Signals from hydrophones at depths 9 m and 18 m did not show a marked difference in received levels. These levels varied from a high of 177 dB re 1 microPascal at range 1.62 km to a low of 148 dB at 9.27 km. Regression analysis to fit an equation for received level to 38 measurements did not result in a physically satisfactory model as the range-dependent term (for absorption-like losses) was positive (indicating a gain in received level per unit range) and the spreading loss term was unusually large. Evidently the acoustic transmission loss must be modelled with a more

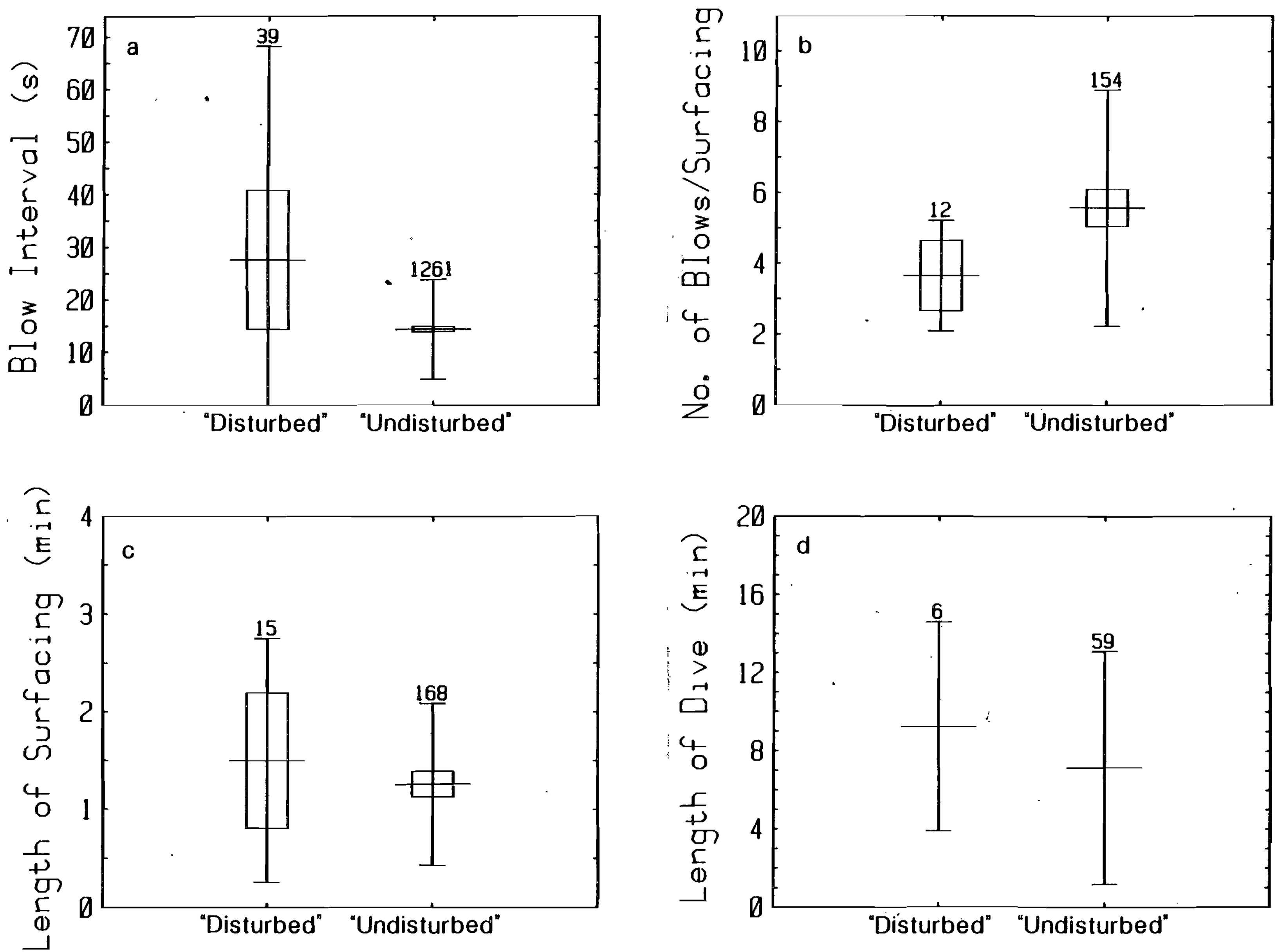


Figure 20. Comparison of respiration, surfacing and dive characteristics for whales possibly disturbed by industrial seismic activity and those presumably undisturbed, for non-calves. Presentation as in Fig. 13.

sophisticated process than simple spreading and linear range dependence. However, a reasonable description of the data was obtained by forcing the spreading loss term to be -20 log(R), corresponding to spherical spreading. Then the range dependent term was -0.97 dB/km. An additional interesting feature of the data was a sudden shift in the dominant frequency between ranges of 3.7 km and 4.1 km. For ranges less than and including 3.7 km, the dominant frequency was between 60 and 80 Hz. For 4.1 km and greater ranges the dominant frequencies were greater than 200 Hz. Methodology and further results are presented in Appendix B.

DISCUSSION

The extremely heavy ice conditions in the Alaskan Beaufort Sea in fall of 1983 made possible relatively intensive monitoring of geophysical survey vessels. More grids were begun this year (22) than in 1982 (16), and the modified grid pattern allowed for somewhat greater coverage of the areas around the vessels. The narrowness of the open-water corridor that existed from late August through early to mid-September greatly limited the operating range of the vessels and enabled us to monitor more vessels with greater frequency, as well as achieve good coverage of the available open water near shore.

The extensive, often closely-packed ice forced geophysical vessels to work primarily inshore of the 20-m depth contour, and thus shoreward of the fall migration route, which was offshore and centered along 71°00'N. Whales were not seen near vessels, except east of Barter Island where open water persisted, and in outer Harrison Bay which generally had lighter ice coverage than areas to the east. The majority of whales were found in offshore areas in 5/10 to 7/10 ice, a considerable distance from active geophysical vessels. This circumstance limited opportunities to observe bowhead behavior in the presence of geophysical sounds or to conduct controlled disturbance experiments with cooperating geophysical vessels.

It is possible that the heavy ice coverage in fall 1983 affected bowhead behavior as well as the migration route. In 1980, a year of similarly heavy ice, Ljungblad (1981) reported sightings of 49 bowheads during the entire fall season in the Alaskan Beaufort Sea (August 30 to October 25). In that year, transect and search surveys (there was no geophysical vessel monitoring program at that time) ranged east of 147°W and rarely went north of 70°45'N. In 1983, surveys extended further offshore to 72°N with the majority of sightings occurring along the 71°00'N line. In 1983, 76% of the monitoring efforts, from August 18 to September 23, focused on areas south of 70°45'N, as that was where the geophysical vessels were operating. Yet only 14 of the whales (29%) seen during that period were located south of 70°45'N. The majority of sightings, 34 whales (71%), were located north of 70°45'N. In 1980 and 1983, ice covered many of the potential feeding areas normally found nearshore in early fall (Lowry and Burns, 1980; cf. Ljungblad et al. 1983; Reeves et al. 1983). This ice coverage may have reduced productivity of the available food sources nearshore

(Schell et al. 1982) and caused most bowheads to follow a more direct and offshore route to the Chukchi Sea. The few groups of whales found nearshore apparently feeding may have been simply searching for prey, thus explaining their brief stay in these areas during heavy ice years.

Ice coverage also may have affected the rate of movement of bowheads across the Alaskan Beaufort Sea in 1983. During previous years of light-ice coverage, behavioral data shows that whales moved into the nearshore zones of the Alaskan Beaufort Sea in mid-September. As they passed through waters near Barter Island, they frequently stopped for extended periods apparently to feed (Ljungblad et al. 1983). In 1981 and 1982, whales were judged to be milling or possibly feeding until late September. Whales were observed traveling west in 1982 on September 28 (Reeves et al. 1983). In 1983, however, whales were seen traveling westward and offshore through heavy ice throughout most of September. Although a few observations of milling or possible feeding occurred in late August and early to mid-September (e.g. August 31 and September 2, 6, 16 and 18), most whales seen in Alaskan waters were judged to be traveling west. In late September (26 through 29) groups of bowheads were seen milling, searching for prey, and possibly feeding in the areas of Barter Island and Flaxman Island. On September 30, a final search survey of areas east of Barter Island to west of Flaxman Island accounted for no sightings. This suggests that the few whales seen in the coastal areas were making brief stopovers to feed or search for prey, then resuming their movement to the west.

Of the swimming estimates obtained, five were of individuals and two were of "groups" of whales. This speed estimate method is limiting due to difficulty in locating reidentifiable bowheads, and to difficulty in resighting any bowhead once it has entered an area of heavy (7/10 to 9/10) ice coverage. Many whales on which an initial position was taken were not sighted again. Absolute values for rate of movement probably cannot be accurately determined from aerial observations, but swimming speed estimates derived from this method can be compared to the more accurate estimates obtained from theodolite readings from shore-based stations (Rugh and Cubbage, 1980; Würsig et al. 1982).

Rate of movement estimates taken from bowheads in fall 1983 vary considerably. The method utilized in collecting these rates makes possible some sources of error, including accuracy of obtaining the precise position and time of a particular sighting or resighting, degrees of confidence in reidentifying particular whales and assumptions concerning "group" movement over a period of time. It is important to note that these rates of movement or swimming speeds are estimates only. Nonetheless, they can be compared to other estimations of swimming speeds collected from bowhead whales during spring and fall migrations, and in summer feedings areas in the Canadian Beaufort Sea. Koski and Davis (1980) estimated mean swimming speeds for bowheads migrating along the Baffin Island coast in fall to be 4.7 ± s.d. 1.6 km/h based on aerial observations and 5.0 ± s.d. 1.3 km/h based on theodolite observations from shore. Ljungblad (1981), using similar techniques as those used in fall 1983, estimated the speed of westward migrating whales in September 1980 to be 2.8 to 5.6 km/h in ice conditions of 7/10 to 9/10 coverage. Swimming speeds during the spring migration have been estimated at 1 to 11 km/h (Carroll and Smithhisler, 1980), 4.8 to 5.9 km/h (Braham et al. 1979) and 3.1 ± s.d. 2.7 km/h (Braham et al. 1980), and rates for bowheads at the surface in summer feeding areas have been estimated by theodolite readings from shore stations to be 5.1 ± s.d. 2.93 km/h (Würsig et al. 1982). Three of the rates we estimated for individual whales were within previous ranges, but two estimates (whales 2 and 4, Table 8) were higher.

The slowest rate of movement, 2.5 km/h, was taken from a possibly feeding bowhead less than 1 km from shore east of Barter Island. This is a suspected feeding area for bowheads (Ljungblad et al. 1984), and as whales migrate through this nearshore zone of the Alaskan Beaufort Sea, they may slow or stop their westward movement to take advantage of potentially high densities of nearshore prey which may vary seasonally depending on ice conditions (Schell et al. 1982).

Although controlled seismic/bowhead whale behavior response experiments were not successfully carried out in 1983, data on undisturbed behavior of primarily migrating bowheads during the "heavy-ice year" of 1983 are useful for year-to-year comparisons. Data on undisturbed migrating behavior also provide a baseline against which to compare previously collected data on potentially undisturbed feeding behavior. In spite of the small sample sizes for some variables, it has been instructive as well to compare the trends in data on potentially disturbed versus undisturbed whales in this study with corresponding trends in other previous studies.

Comparisons with Fall Observations in other Years

Substantial quantitative data on bowhead behavior in the Alaskan Beaufort Sea in 1982 were primarily collected on feeding whales (Reeves et al. 1983). The 1982 data were collected in a manner similar to that in 1983, but they were grouped and analyzed in somewhat different ways. The differences between behaviors observed in 1982, a light-ice year (feeding), and 1983, a heavy-ice year (migrating) imply that between-year comparisons and similarities should be interpreted broadly. Cows (= mothers) with calves were grouped separately from other non-calves and called "adults" in the 1982 analysis. Two, rather than four depth categories, and two, rather than three association categories were used. The whales observed in 1982 were not assigned to different categories for analysis of general behavior, and 1982 observations were not classified according to time of day. In 1982, mean blow intervals per surfacing, rather than blow intervals _per se_, were used in the analysis, thus reducing sample sizes. In 1982, all observations were made in open water, whereas in 1983 many observations were made in conditions of 5/10 to 8/10 ice coverage. None of the whales for which quantitative data on behavior were acquired in 1982 were judged to be traveling, but many were milling and possibly feeding. In 1983, the majority of observations were of traveling whales.

In spite of these differences, some comparisons can be made between the two data sets. The mean number of blows per surfacing, mean length of surfacing, and mean dive time for undisturbed other non-calves (not including cows) were similar in the fall 1982 and fall 1983 studies (Table 12). The mean interval between blows was similar for undisturbed other non-calves as well: 14.0 ± s.d. 8.22s, n = 1174, in 1983, and 12.54 ± s.d. 2.97s, n = 41 (mean of means), for "adults" (not including cows with calves) in 1982. The trend in 1983 for cows to have longer blow intervals than calves and other non-calves is consistent with data on all whales (potentially disturbed and undisturbed) in 1982, but the trend is reversed when only undisturbed whales are considered for 1982 (Reeves et al. 1983, Table 9). This difference may not be meaningful, however, because of differences in general behaviors between the two years.

All calves and mothers (=cows) observed in 1983 were undisturbed and therefore were compared to nonseismic adults, cows and calves from 1982 (Table 12). Blow intervals for calves tended to be shorter than for

Table 12. Comparison of summary statistics for the principal surfacing, respiration and dive variables for bowheads in fall 1982 and fall 1983. Data for 1982 from Reeves et al (1983).

		Blow Interval (sec)			Number of Blows per Surfacing			Length of Surfacing (min)			Length of Dive (min)		
Year	Age Class	$\bar{x}$	s.d.	n	$\bar{x}$	s.d.	n	$\bar{x}$	s.d.	n	$\bar{x}$	s.d.	n
1982	Adults--nonseismic	12.54	2.97	41*	6.87	3.14	30	1.36	.59	31	5.98	3.02	6
1983	Other noncalves--presumably undisturbed	14.00	8.22	1174	5.40	3.20	143	1.21	.777	157	6.87	6.164	51
1982	Cows with calves--nonseismic	11.78	1.37	5*	8.60	0.55	5	1.75	.29	5	10.12	4.73	7
1983	Mothers--presumably undisturbed	17.60	6.49	87	7.20	4.38	11	2.11	1.022	11	8.63	4.256	8
1982	Calves--nonseismic	15.53	7.71	4*	9.67	2.89	3	2.28	1.45	3	-	-	-
1983	Calves--presumably undisturbed	15.00	14.69	104	8.50	4.25	11	2.10	1.077	12	8.57	4.127	8

*Mean of means, as calculated for blow interval data in 1982.

cows, and calves had more blows per surfacing and nearly equal surface times than did cows in 1983, none of which were seen in fall 1982. Comparing cows and those whales designated as other non-calves in 1983, cows were found to have longer blow intervals, more blows per surfacing and longer surface and dive times than did other non-calves. These same trends, with the exception of blow intervals, were statistically significant in fall 1982 (Reeves et al. 1983). Sample sizes for dive time are small in both years' data sets, but they are adequate to suggest the interesting and testable hypothesis that cows and calves, while blowing more times per surfacing and surfacing for longer periods than other whales, dive for longer periods as well.

The most important comparison, in the present context, concerns the behavior of potentially disturbed vs undisturbed whales for the two years. Blow interval appeared to be longer for whales possibly disturbed by geophysical activity than for whales undisturbed in 1983. A similar trend in the data was observed in fall 1982, when adult bowheads in the presence of sounds had longer blow intervals than those observed in the absence of seismic sounds (Reeves et al. 1983). Although we found in 1983 that the number of blows per surfacing was significantly reduced for potentially disturbed whales, the data for 1982 showed no such trend. In 1982, surface times, a characteristic positively correlated to number of blows per surfacing, was significantly longer for potentially disturbed than for undisturbed non-calves exclusive of cows. In 1983 the trend was also for potentially disturbed non-calves to have somewhat longer surface times than undisturbed non-calves (Fig. 20c), although the difference was not statistically significant. The trend in both years for the small samples of dive times was toward longer dives by potentially disturbed whales, but the potentially disturbed vs undisturbed differences were not statistically significant.

Although the data for respiration, surfacing and dive characteristics are difficult to interpret relative to depth of water, there was a trend for blow intervals and length of surfacing to be greater in deeper (> 90 m) water in 1983. This same trend was observed in fall 1982, when adults in deep water had significantly longer surface times than those in shallow water (Reeves et al. 1983). Number of blows per surfacing is also higher in deeper than in shallower water, with values around 5 for water depths less than about 100 m, and values around 7 in deeper water in 1983. This same trend was seen in 1982.

There is almost certainly a bias against lengthy dive times in the 1983 data on "traveling" (or "migrating") whales. Although no attempt was made to quantify the difference, all observers agreed that our success at relocating "traveling" whales in ice was poor in comparison to our success at relocating "feeding" whales in open water. In heavy ice, there were numerous times when whales could not be relocated within about a half-hour of searching. Thus, long dive times (i.e. those of 15-30 minutes or longer) would likely be under-represented in the sample for "traveling" whales. This bias may, at least, partially account for the tendency of dive times to be shorter for column feeding whales (which happened to be in shallower water) than for "traveling" whales (which happen to be in deeper water).

Qualitative comparisons can be made between the behavior of bowheads from 1979 to the present, when monitoring of the migration through the Alaskan Beaufort Sea began (Ljungblad et al. 1984). In general, the five years from 1979 to 1983 can be classified as either "heavy-ice years" (1980 and 1983) or "light-ice years" (1979, 1981 and 1982), dependent upon ice conditions that prevailed during the month of September.

During the three "light-ice years" of 1979, 1981 and 1982, feeding whales in nearshore areas were predominant. Heavy ice was absent from the study area (from shore north to 72°N) throughout September. In 1979 relatively large numbers of bowheads (155 sighted) were present nearshore and not obviously traveling west (average heading of 111°T) until as late as October 14 (Ljungblad et al. 1980). The westward migration did not begin until approximately September 26, when two bowheads were seen traveling west near Flaxman Island. Apparent feeding behavior was observed from near Demarcation Bay west to Flaxman Island until late September.

In 1980, heavy-ice of 1/10 to 5/10 coverage was present from shore to just outside the 20-m contour, and 7/10 to 9/10 ice coverage was encountered farther offshore (Ljungblad, 1981). Grease ice began forming on September 20, and by September 24 coastal areas were generally covered with new ice. Nearly all whales seen in September of 1980 were swimming west. Only two groups sighted were thought to be feeding; both were seen east of Barter Island on September 14. One of these groups was within 2 km of the coast.

In 1981, a light-ice year, apparent feeding behavior was seen from the second week of September on, nearshore between Barter Island and Demarcation Bay (Ljungblad et al. 1982). By late September, the bowhead distribution was along the 20-m contour from Demarcation Bay west to Flaxman Island. Feeding behavior slowly tapered off in early October as more whales began moving west.

The 1982 season was similar in most respects to that of 1979 and 1981, when comparing ice conditions, behavior, and nearshore distribution (Ljungblad et al. 1983; Reeves et al. 1983).

In 1983, ice conditions were even more severe near the coast than in 1980, with one period (September 5-14) when heavy (9/10) ice actually was pushed against shore between Barter Island and the Alaska-Canada border. Whales were seen swimming west, i.e. "migrating", as early as September 3. A high proportion of sightings were in ice of 5/10 or more coverage, and most whales in such circumstances were traveling west. However, some feeding behavior was observed in broken floe ice in early to mid-September and in newly formed slush and grease ice nearshore in late September. Whales were still moving through the Alaskan Beaufort Sea until mid-October, but no feeding activity was observed there after September 29 (Ljungblad et al. 1984).

<u>Comparisons with Summer Observations</u>

Because of the relative lack of long-term data, qualitative comparisons of whale behavior between fall in the Alaskan Beaufort Sea and summer in the Canadian Beaufort Sea are broad generalizations at best. Sporadic aerial activity and possible bottom feeding and water-column feeding were observed throughout September in the Alaskan Beaufort Sea during open water years, and are similar to descriptions of these behaviors in August and early September off the Tuktoyaktuk Peninsula, Canada (Würsig et al. in press). Just as in summer, groupings of whales within a 10 to 50 km^2 area may all be engaged in similar activity at a time. This was especially evident during possible water-column feeding seen on September 26 and 29. Fewer social interactions occurred in the western Beaufort Sea in September than in the eastern Beaufort Sea in August (Würsig et al. 1984). The frequency and intensity of social interaction in September in the Beaufort Sea appear relatively low when compared to that observed in early spring in the northern Bering Sea (e.g., Everitt and Krogman, 1979; Carroll and Smithhisler, 1980; Ljungblad et al. 1984), indicating there may be a difference in the degree of socializing between the Bering and the Beaufort Sea. Much westerly directed travel is observed when heavy ice is present in September in the western Beaufort Sea, but relatively little has been seen in August in the eastern Beaufort Sea (Würsig et al. in press).

Respiration, surfacing and dive characteristics in fall 1983 were remarkably similar to those of 1980-1982 combined data of studies in the eastern Beaufort Sea in August and early September, especially in regard to surface time

(1.33 ± s.d. 1.095 min, n = 168 in fall 1983; 1.30 ± s.d. 0.960 min, n = 368 for the summer studies) (Würsig et al. 1983). The trend for decreasing number of blows per surfacing, decreasing length of surfacing, and decreasing length of dive as the day advanced is of interest, for no such apparent diurnal trend was noticed during summer observations (Würsig et al. in press). It is possible, though, that time of day is not the primary variable responsible for this apparent trend.

Other comparisons between summer and fall observations show similar trends in increased blow intervals, increased number of blows per surfacing and increased surface times in deeper water. Length of dive does not show as clear a trend, since the longest dives in September actually occurred in water less than 30 m deep while longest dives occurred in >100 m depth in August 1982 (Würsig et al. 1983). The lack of consistency in this characteristic between the two studies probably is due to the fact that much of the data on dive times in the present study were from whales apparently water-column feeding in shallow water near the end of September, while such feeding appears to have occurred in deeper water during the summer studies.

In the present study, blow interval appeared longer for whales potentially disturbed by seismic activity than for whales undisturbed. Similar situations occurred during two summer 1982 experiments with a 40 cu. in. airgun 2.5 to 5 km from bowhead whales. Blow intervals rose by 3 to 8 seconds from a pre-disturbance value to a disturbance value. Number of blows per surfacing was significantly lower for potentially disturbed than for undisturbed whales, and this too was the general pattern for whales in the presence of seismic sounds in summer (Richardson et al. 1983). Although Richardson et al. (1983) found a tendency for reduced lengths of surfacings and dives in the presence of seismic noise, we observed an opposite trend. Data collected from 1980-83 on bowheads in the Canadian Beaufort Sea now indicate that blow intervals, number of blows per surfacing and surface times are not significantly different between undisturbed bowheads and bowheads six kilometers or further from active geophysical vessels (Richardson et al. 1984).

Comparisons with Observations During Spring Migration

Behavior of bowheads during their spring migration through the Bering Strait, along the Chukchi sea coast of Alaska, and into the Beaufort Sea has been studied by aerial (Ljungblad et al. 1983, 1984), shore-based (Rugh and Cubbage, 1980), and ice-based (Carroll and Smithhisler, 1980) observers. Most descriptions of behavior in spring are qualitative, but there is some quantitative information, particularly by Carroll and Smithhisler (1980), which can be compared to that collected in fall 1983. In that study, observers were stationed at camps on the fast ice between Pt. Hope and Pt. Barrow, watching whales move northeast through the nearshore lead. In this situation, virtually all the whales were headed in the same direction and were moving at speeds of 1 to 11 km/h. Carroll and Smithhisler used somewhat different terminology in describing the respiration, surfacing and dive characteristics of bowheads. Each time a whale surfaced during a "dive sequence" (equivalent to our surfacing period), this was scored as a "roll". They noted that a blow is not visible every time a whale rises and so data on blows per dive sequence may have a slight downward bias. Their results indicated that bowheads surfaced 2 to 14 times in a dive sequence. For undisturbed whales the mean number of rolls per dive sequence was 6.57 ± s.d. 3.08, n = 63; the mean number of blows per "rise" (= dive sequence?) was 6.53 ± s.d. 2.84, n = 41.

Undisturbed non-calf bowheads in September 1983, many of which were traveling in the opposite direction from those observed in spring by Carroll and Smithhisler, had a mean number of blows per surfacing of 5.6 ± s.d.3.33, n = 154. Observations in September 1982, when the Alaskan Beaufort Sea was ice-free, resulted in means of 6.87 ± s.d. 3.14, n = 30 for undisturbed non-calves exclusive of cows and 8.60 ± 0.55, n = 5 for cows (Reeves et al. 1983, Table 9). From these data, it would appear that the number of blows per surfacing of bowheads differs little between the spring and fall phases of their migration.

Carroll and Smithhisler (1980) also calculated the "mean duration of a rise" for eight bowheads by adding the mean time above the surface to the mean time between blows. This value was assumed to represent "the time between sounding dives when a whale was at or near the surface and presumably visible from an aircraft". Thus, it may correspond closely to values for length of surfacing. Their mean of 1.52 min is in fairly good agreement with the mean of 1.33 ± s.d. 1.095 min, n = 168, for undisturbed non-calf whales in September 1983, and the 1.36 ± 0.59 min, n = 31, mean for undisturbed non-calves exclusive of cows in September 1982 (Reeves et al. 1983, Table 9).

Sounding dives were not precisely defined by Carroll and Smithhisler (1980), but it is assumed they used criteria similar to those discussed by Rugh and Cubbage (1980). Thus, dives lasting 75 seconds or longer were probably considered sounding dives. The estimated mean duration of sounding dives for the study by Carroll and Smithhisler was 15.6 ± s.d. 5.0 min, n = 63. A separate mean of

6.6 min was calculated for "three cow-and-calf pairs". In September 1983 the mean length of dives of undisturbed non-calf bowheads was 7.11 ± 5.943 min, n = 59. Unlike Carroll and Smithhisler, we found that undisturbed cows and calves dove, on average, slightly longer than did undisturbed non-calves (Figure 17d), although this trend was not significant. The dive time data from September 1982 (Reeves et al. 1983, Table 9) agrees more closely with data from September 1983 than with the spring data of Carroll and Smithhisler: mean dive time of 5.98 ± s.d. 3.02 min, n = 6, for undisturbed non-calves exclusive of mothers, and 10.12 ± s.d. 4.73 min, n = 7, for undisturbed cows (Table 12).

Quantitative data on dive times were also given by Rugh and Cubbage (1980). These refer to whales seen migrating past Cape Lisburne, Alaska, in the Chukchi Sea from April 2 to June 7, 1978. The animals were generally heading northeast and traveling at a rate of 4.7 ± 0.6 km/h within 14.8 km of shore. The three sounding dives recorded had a mean duration of 7.53 min, similar to data from September 1983.

CONCLUSIONS

Heavy ice conditions persisted in the Alaskan Beaufort Sea during the entire fall 1983 season and precluded controlled seismic/bowhead behavior experiments, the major objective of this study. However, the experience gained during this season allowed for evaluation of the conditions necessary under which the proposed seismic experiments would be likely to produce meaningful results. During heavy ice years, seismic vessels must operate in limited areas and their movements are severely restricted. Additionally, observations from this and previous studies (Ljungblad, 1981; Ljungblad et al. 1980, 1982, 1983) indicate that in heavy ice years bowhead whales primarily travel (as opposed to mill and feed) through heavy ice and are subsequently difficult to resight and follow for prolonged periods, which would be necessary for documentation during seismic experiments. Therefore, to successfully conduct seismic/bowhead behavior experiments, the following two conditions should prevail:

1. Experiments should be conducted during light ice conditions when seismic vessels would be able to move to specific areas unhindered by sea ice to interact with whales, and,
2. whenever possible, subject whales should be non-traveling, e.g. whales feeding or milling in an area for extended periods of time, to facilitate resighting of individuals and the documentation of any progressive changes in their behavior during an experiment.

Although no seismic/bowhead behavior experiments were conducted, data relevant to the evaluation of the impact of seismic vessel noise on the behavior of bowhead whales was obtained. Information on ice conditions prevalent during the 1983 season, geophysical vessel activity, and measurements of waterborne seismic survey signals were obtained as well as information on rates of movements, vocalizations (not reported here) respirations, surfacings, dives, and general behavior of whales in the absence of seismic sounds (undisturbed) and, in a few instances, of whales in the presence of 42-57 km distant seismic sounds (potentially disturbed).

In brief, these data suggest that:

1. During heavy ice conditions, bowhead whales travel primarily through the ice offshore, and less frequently mill and feed in nearshore areas. The reverse is generally observed in light-ice years.

2. The number of blows (respirations) per surface interval of undisturbed and potentially disturbed whales decreased as the day advanced. This possible diurnal pattern should be considered when evaluating blow rates of potentially disturbed whales observed late in the day, as it may confound the evaluation of the impact of seismic noise on whale behavior.
3. Blow intervals, number of blows per surfacing, and length of surfacing tended to be lower in shallow than in deep water.
4. Female whales with calves exhibited longer surface intervals with more blows per surfacing and longer dive intervals than did other whales.
5. Potentially disturbed whales tended to exhibit longer blow intervals, fewer blows per surfacing, but similar duration of surface intervals and lengths of dives than undisturbed whales. However, potentially disturbed whales were only subjected to relatively weak seismic sounds occurring over 40 km distance.
6. Whales which were assumed to be feeding in the water column nearshore exhibited shorter blow intervals, shorter surface times, and longer dive times than did whales traveling (not feeding) farther offshore. However, in light of finding No. 3, it is not clear whether water depth, mode of behavior, or both were responsible for the differences between nearshore feeding and offshore traveling whales.
7. Waterborne seismic survey signals may be modeled as a spherical spreading process, resulting in a range dependent term of -0.97 dB/km from the source, with a shift in dominant frequency component from 60-80 Hz at ranges ≤ 3.7 km to frequencies > 200 Hz at ranges ≥ 4.1 km.

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APPENDIX A

FLIGHT TRACKS AND NARRATIVE SUMMARY OF MONITORING EFFORT, FALL 1983

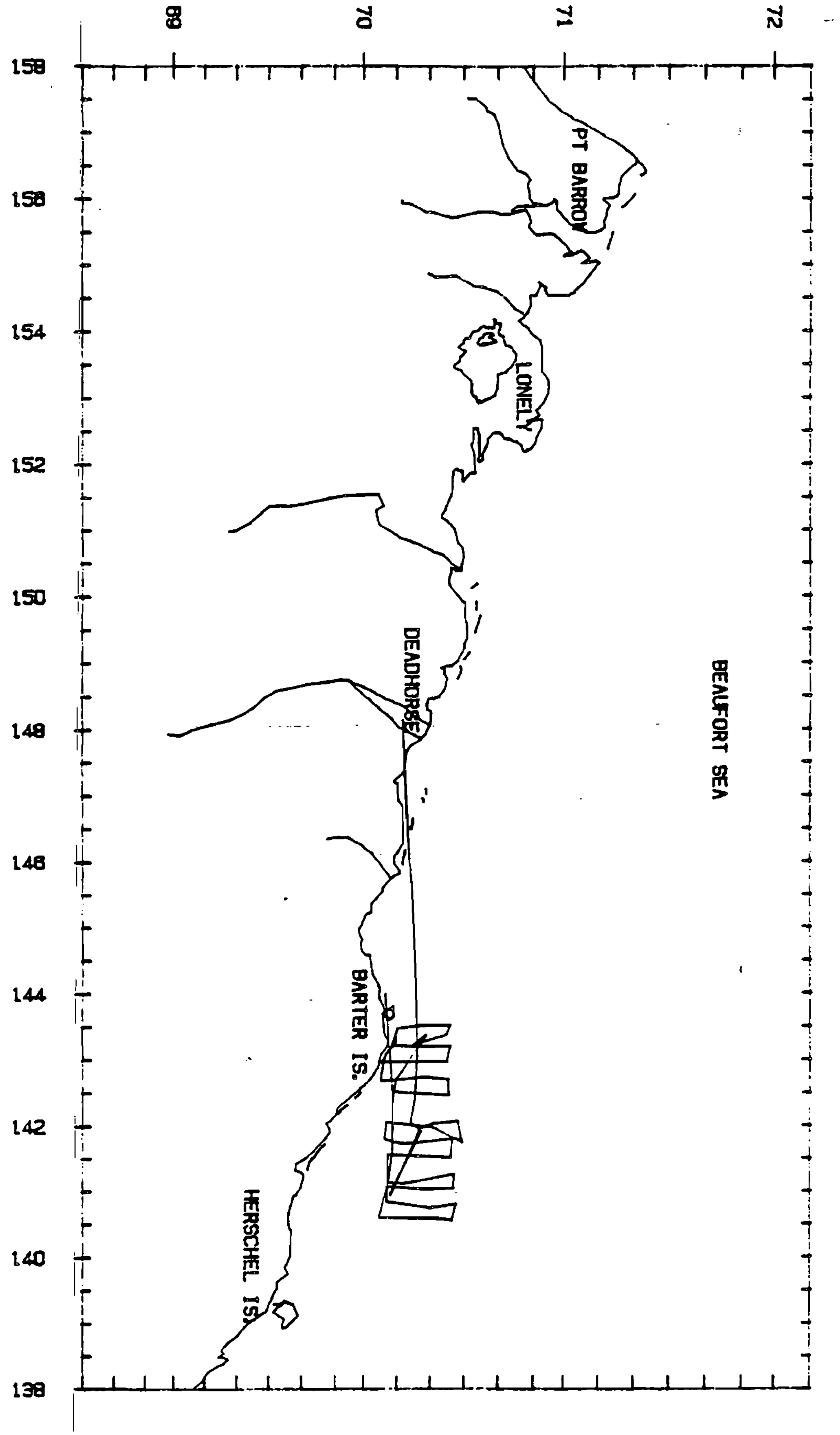
APPENDIX A

Summary of monitoring effort and results, fall 1983. Each of 41 flights is described by a narrative summary, a coded set of data on each sighting, and a map showing the flight track and the positions of bowhead sightings (shown as □). The data codes are keyed as follows:

T#/C#	=	Total bowheads/number of calves included in total.
LAT/LONG	=	Location (latitude N/longitude W) in degrees, minutes, and tenths of minutes.
TIME	=	Alaska Daylight-Savings Time
BEH	=	General activity or behavior (TR = Traveling, MI = Milling, SI = Socially Interacting, BR = Breaching, FE = Feeding, NN = Not Noted)
HDG	=	Heading in degrees (°) magnetic.
ICE	=	Ice coverage in tenths.
SS	=	Sea state (Beaufort scale).
DEPTH	=	Depth in meters (m) at the sighting.
SEISMIC	=	Ensonification present (Yes) or absent (No).
DIST	=	Approximate distance (km) of whales from nearest seismic vessel known to have been shooting at the time.

Flight 1: 18 August 1983

This flight was a grid survey of two geophysical vessels - the GSI Mariner at 70°16.8'N, 141°59.3'W and the Western Aleutian at 70°18.6'N, 143°23.3'W. Ice conditions in the area surveyed were 0/10, and the sea state was Beaufort 1 to 2. Weather was clear with unlimited visibility. No bowheads were sighted. Bearded seals, ringed seals, polar bears, and unidentified pinnipeds were seen.



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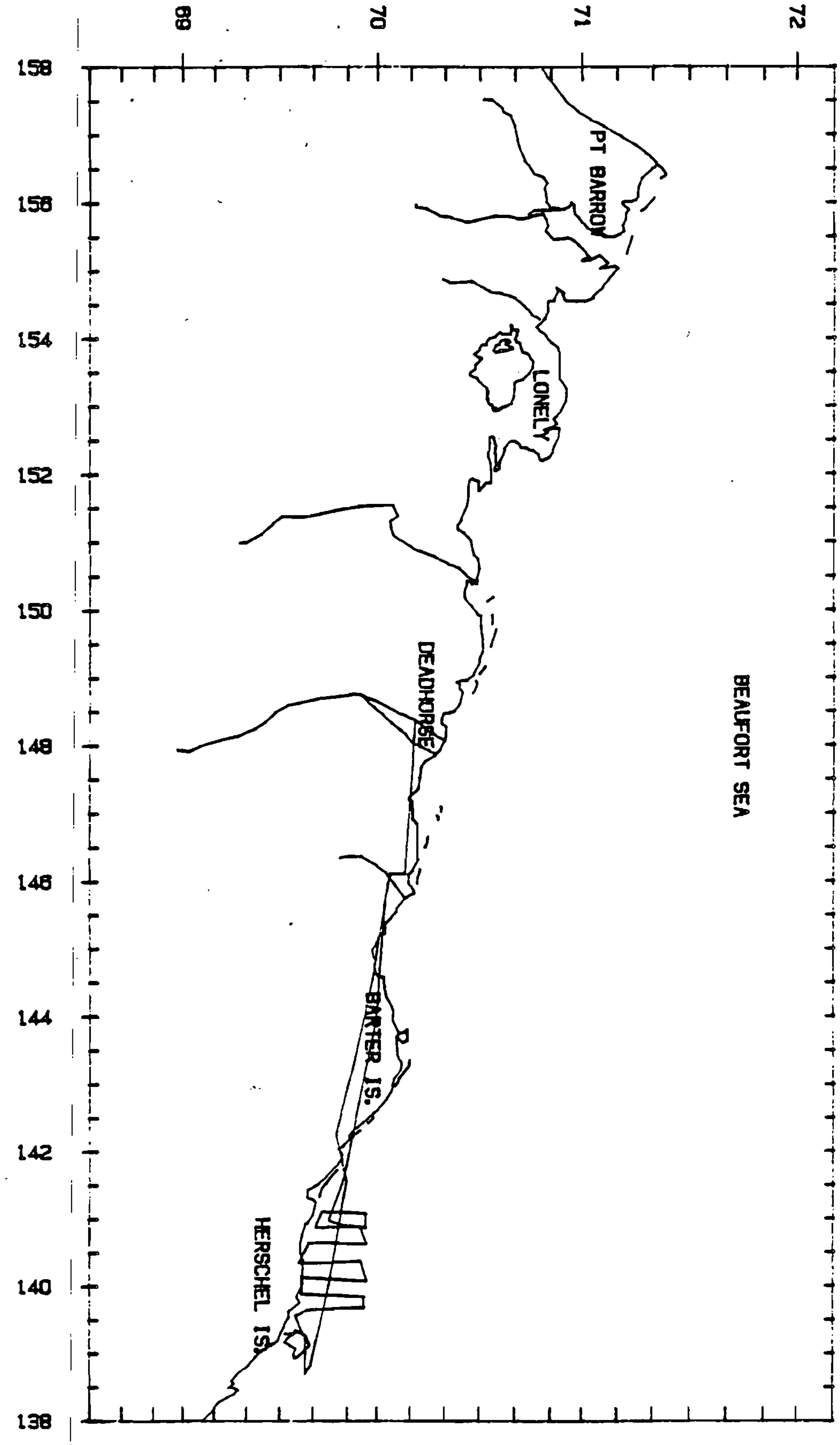
Flight 2: 19 August 1983

This flight was a grid survey of the GSI Mariner at 69°44.3'N, 140°59.4'W, and a search survey north of Herschel Island. Ice was absent in the area surveyed; sea state was Beaufort 2 to 3. Weather was overcast with patchy fog, and visibility ranged from less than 1 km to unlimited. No bowheads were sighted. Bearded and ringed seals were sighted.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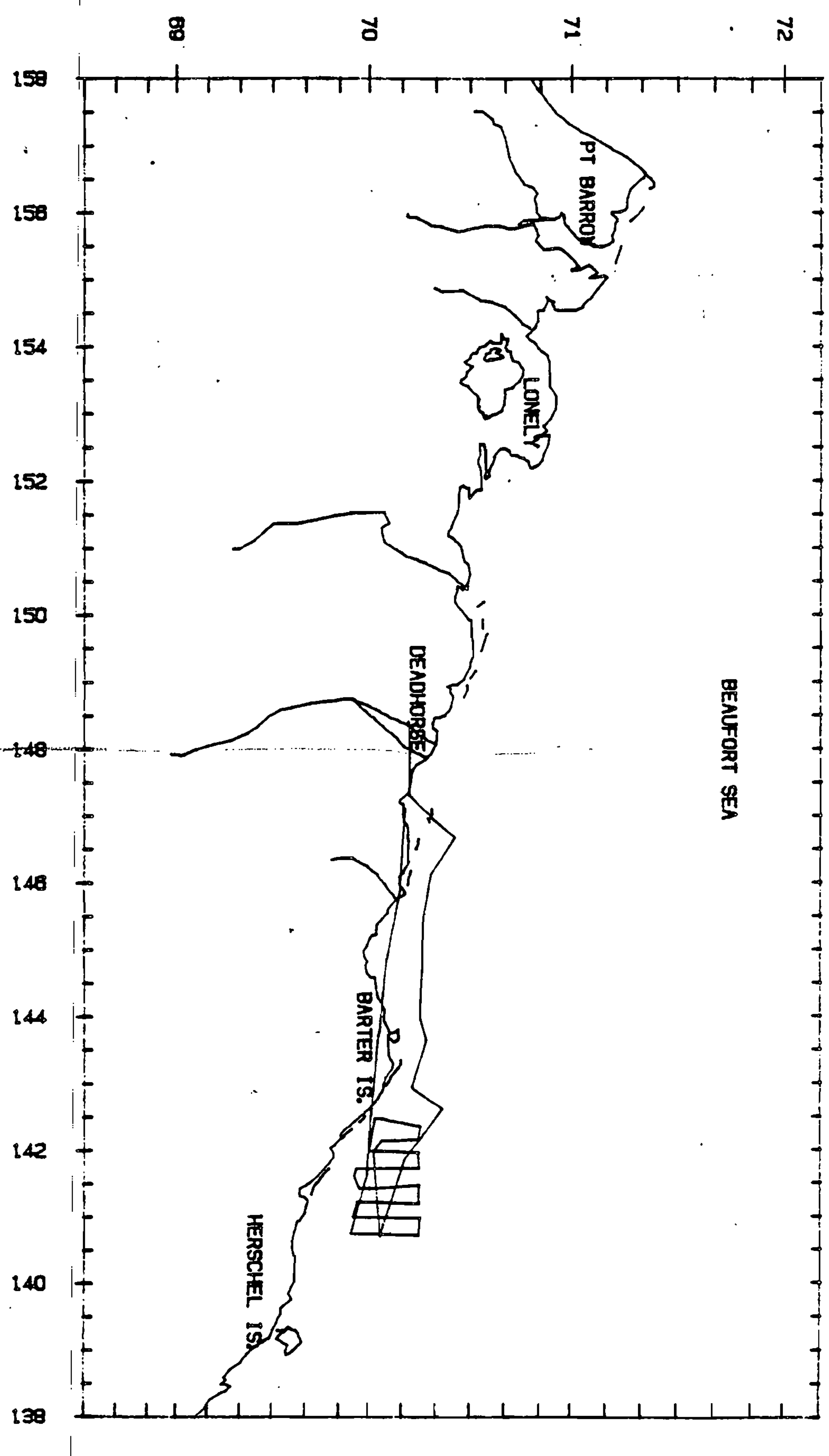
Flight 3: 20 August 1983

This flight was a search survey along the 20 m isobath east from Deadhorse to the Western Polaris at 70°01.3'N, 141°58.3'W, where a grid survey was begun. Ice in the survey area and along the 20 m isobath was 0/10, and the sea state was Beaufort 2 to 3. Weather was clear with unlimited visibility. No bowheads were sighted. Seismic sounds from three geophysical vessels were recorded.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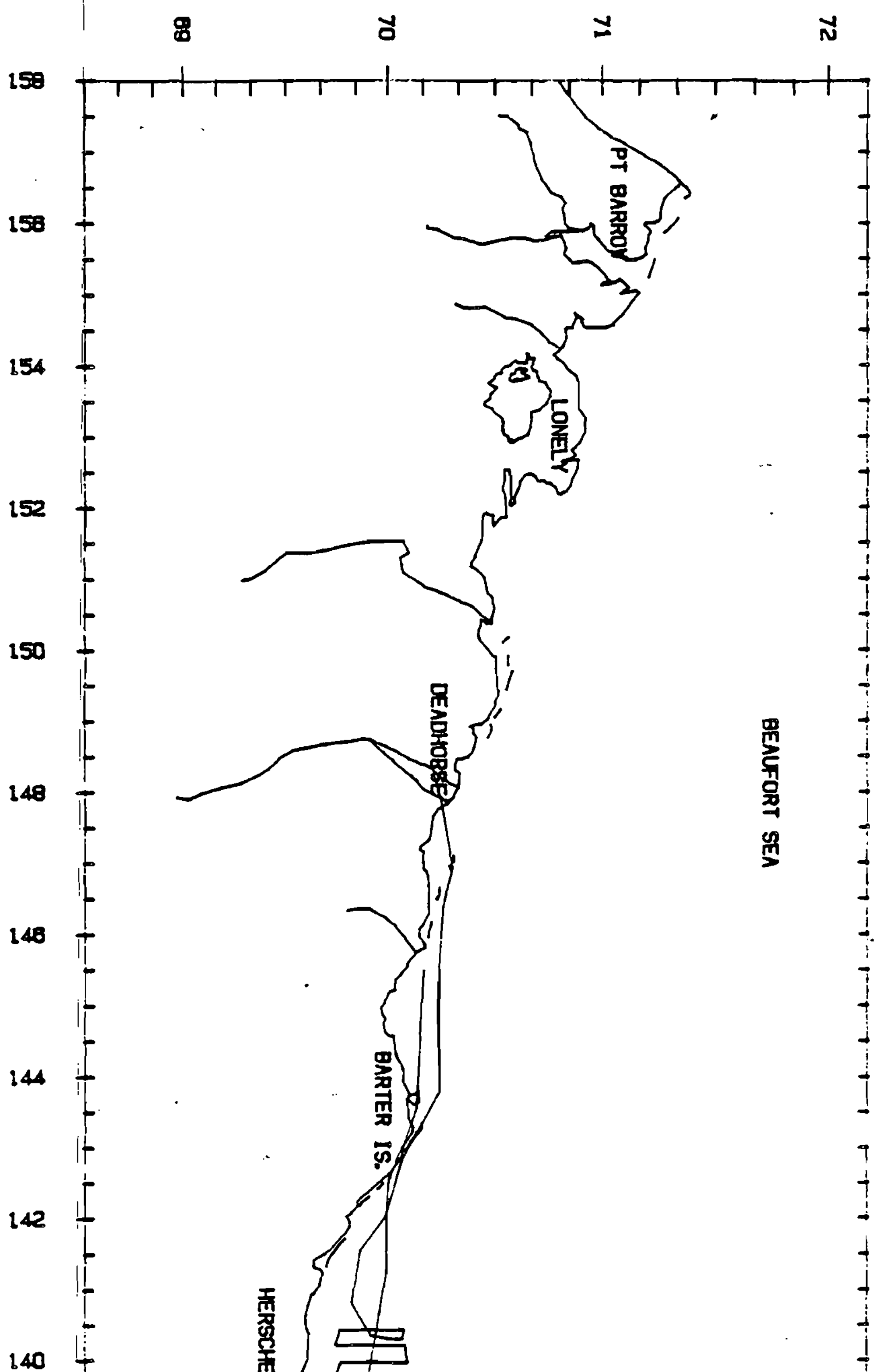
Flight 4: 21 August 1983

This flight was a search survey along the 20 m isobath east from Deadhorse to the GSI Mariner at 69°53.8'N, 140°22.2'W, where a grid survey was begun. Ice conditions along the 20 m line were 3/10 to 4/10 broken floe and 0/10 in the area of the grid. Sea state was Beaufort 2 to 3 in the open-water area and Beaufort 0 along the 20 m isobath. Weather was clear with unlimited visibility. No bowheads were sighted. Fifteen belukhas were seen at 1219 hr (ADT) at 70°00.6'N, 142°34.2'W, just north of Pokak Bay and within 1 km of shore. They appeared to be milling and feeding and were segregated into smaller groups of 2-3 animals. At least two cow-calf pairs were seen. Ringed seals and bearded seals were also seen. Seismic sounds from one geophysical vessel were recorded.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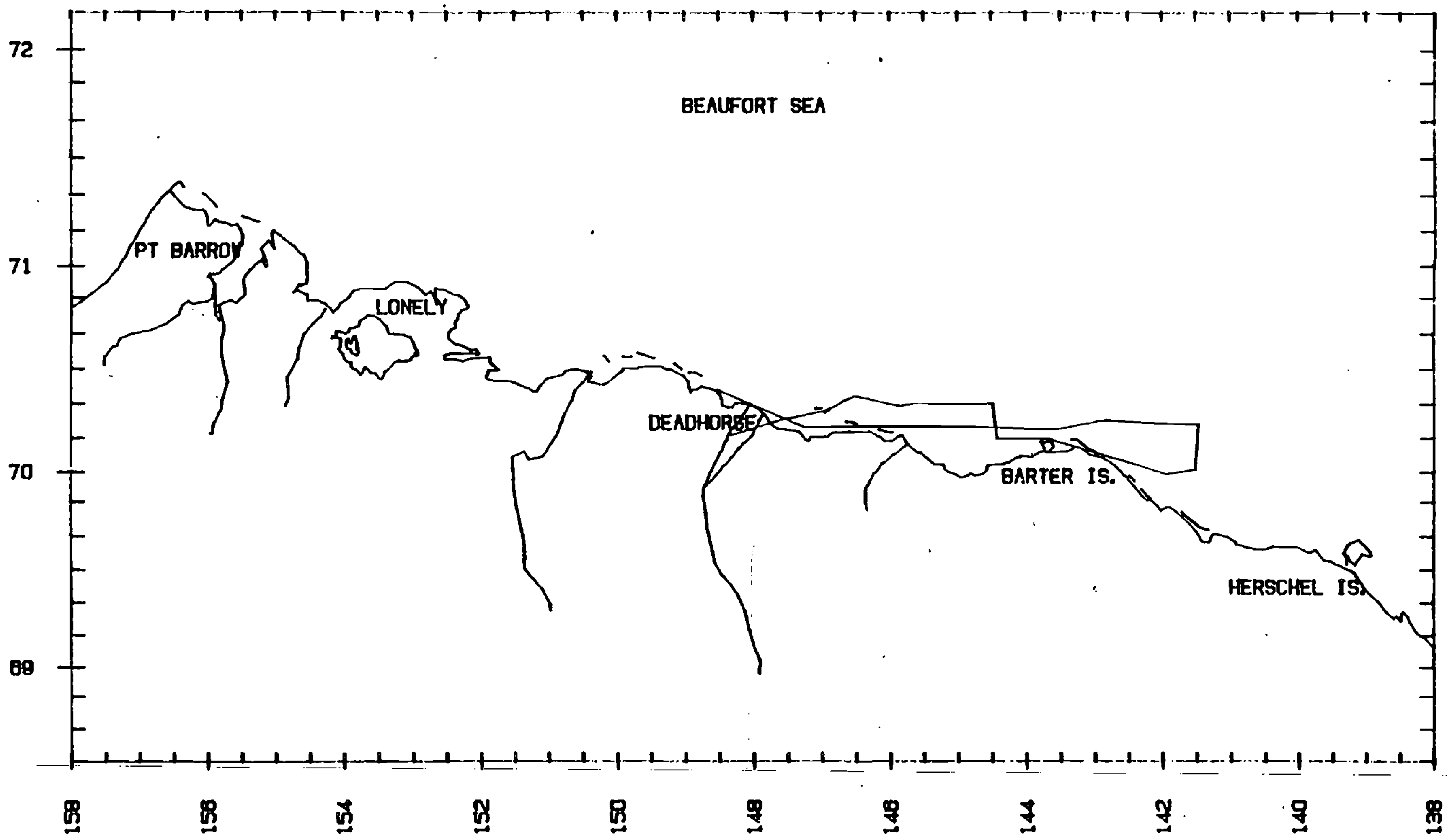
Flight 5: 23 August 1983

This flight was a search survey along the 20 m isobath east from Deadhorse to 141°30'W. No grid surveys were attempted due to low cloud cover and poor visibility. Ice along the 20 m isobath was 5/10 to 7/10 broken floe, and the sea state was Beaufort 0. Ringed seals and a polar bear were seen.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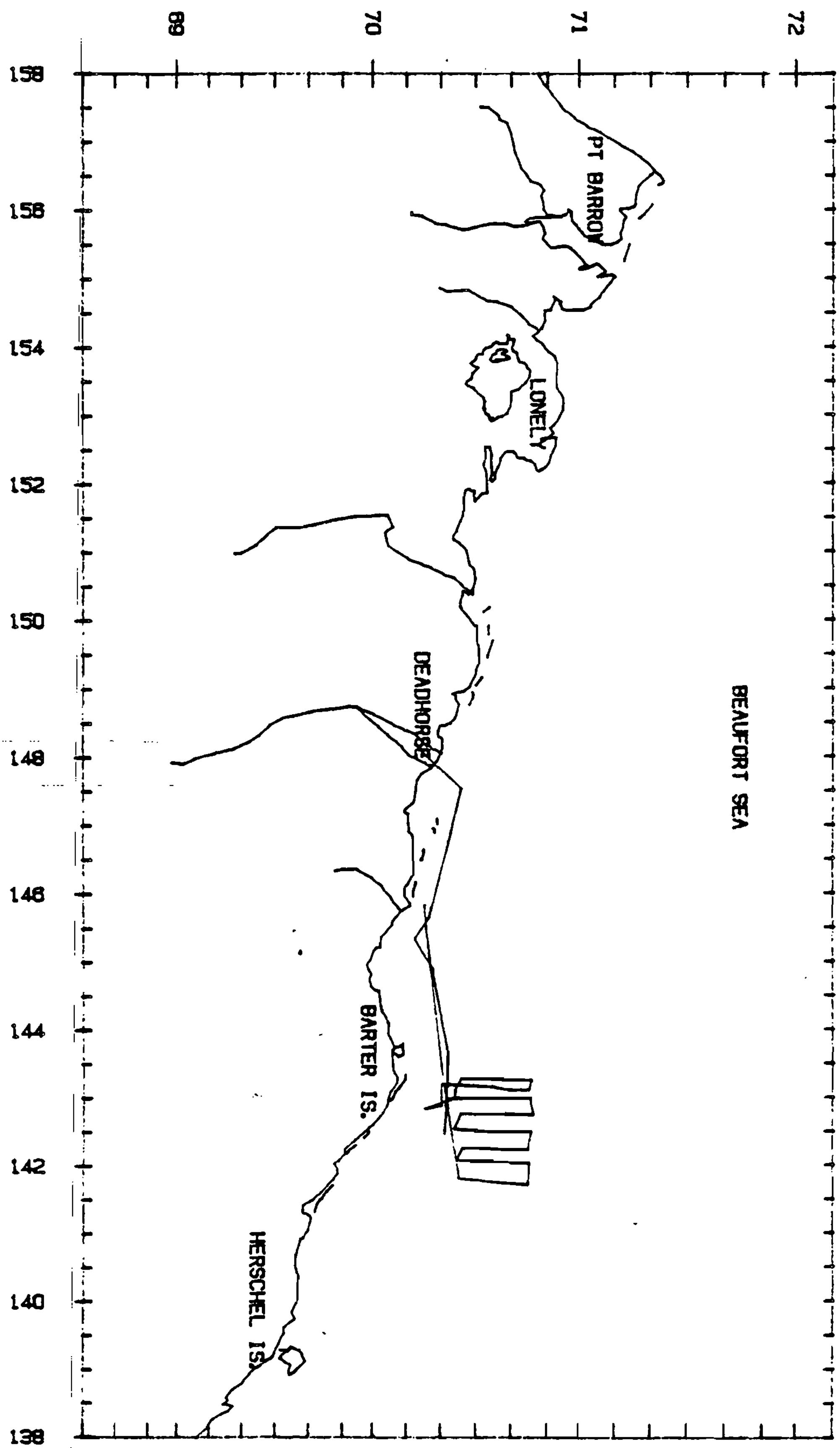
Flight 6: 24 August 1983

This flight was a search survey along the 20 m isobath east from Deadhorse to the Edward O. Vetter at 70°35.1'N, 143°10.7'W, where a grid survey was begun. Ice conditions were 4/10 to 6/10 broken floe along the 20 m isobath, and 0/10 to 5/10 broken floe in the grid survey area. Sea state varied from Beaufort 0 to 3. Weather ranged from partly cloudy with visibility less than 1 km to clear with visibility unlimited. No bowheads were sighted.



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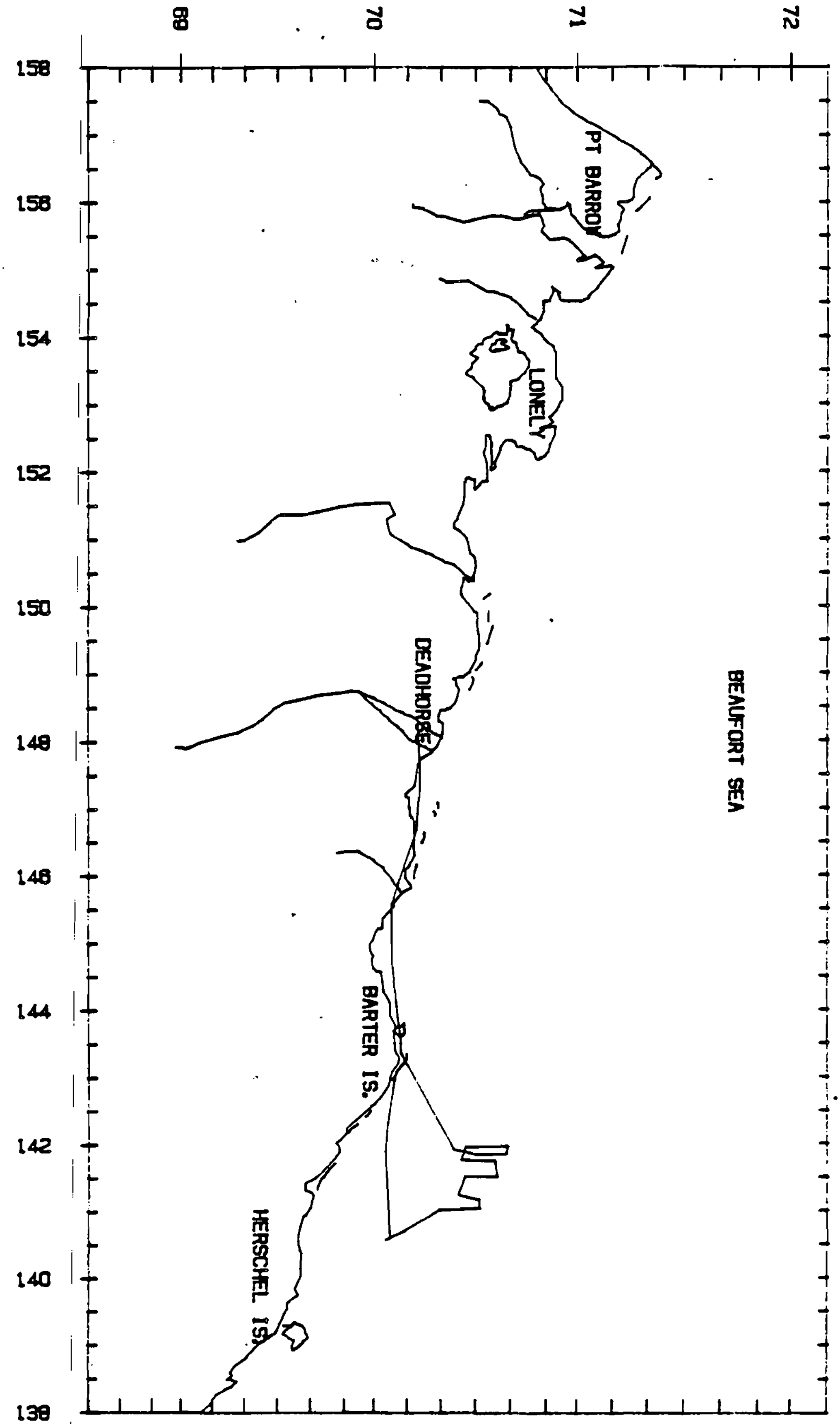
Flight 7: 25 August 1983

This flight was a grid survey of the Edward O. Vetter at 70°29.5'N, 141°51.1'W. Heavy fog, covering most of the Beaufort Sea, caused grid legs to be truncated resulting in incomplete coverage. Ice coverage in the survey area was 0/10; sea state was Beaufort 1. Visibility varied from less than 1 km to 10 km. No bowheads were sighted. Bearded seals were the only marine mammals seen.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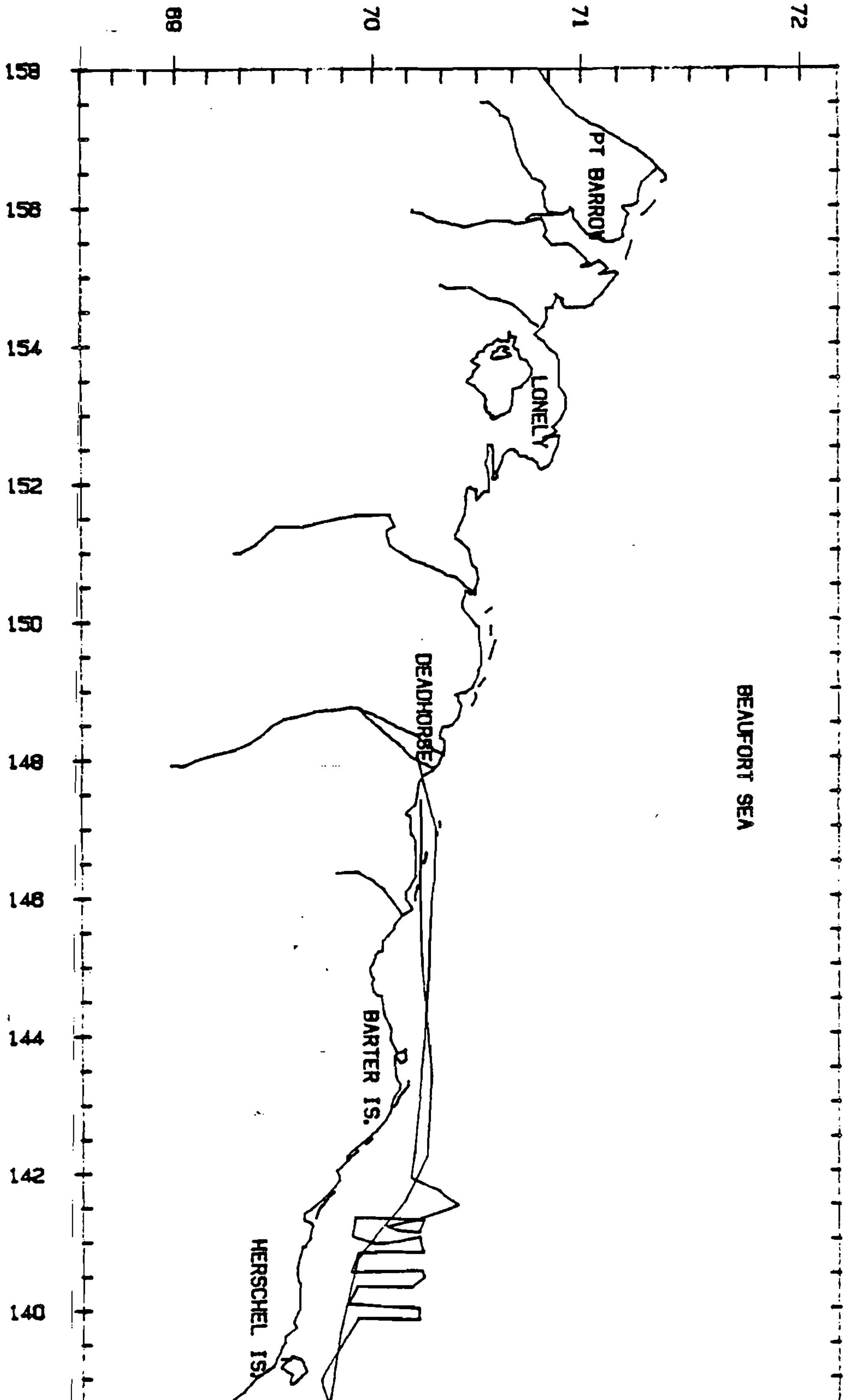
Flight 8: 26 August 1983

This flight was a search survey along the 20 m isobath east from Deadhorse to the the Arctic Star at 70°03.4'N, 141°14.0'W, where a grid survey was begun. Upon completion of the grid, a search was flown north of Herschel Island. Ice was absent in the area of the grid survey and north of Herschel Island. This wide, open-water corridor extended north to 70°25'N, and west to the vicinity of Barter Island, where heavy ice (7/10 to 9/10) close to shore left little open water. Sea state in open areas was Beaufort 1 to 2; in areas with heavy ice, Beaufort 0. Weather was clear with unlimited visibility. No bowheads were sighted. Ringed and bearded seals were seen.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BARTER IS.
HERSCHEL IS.
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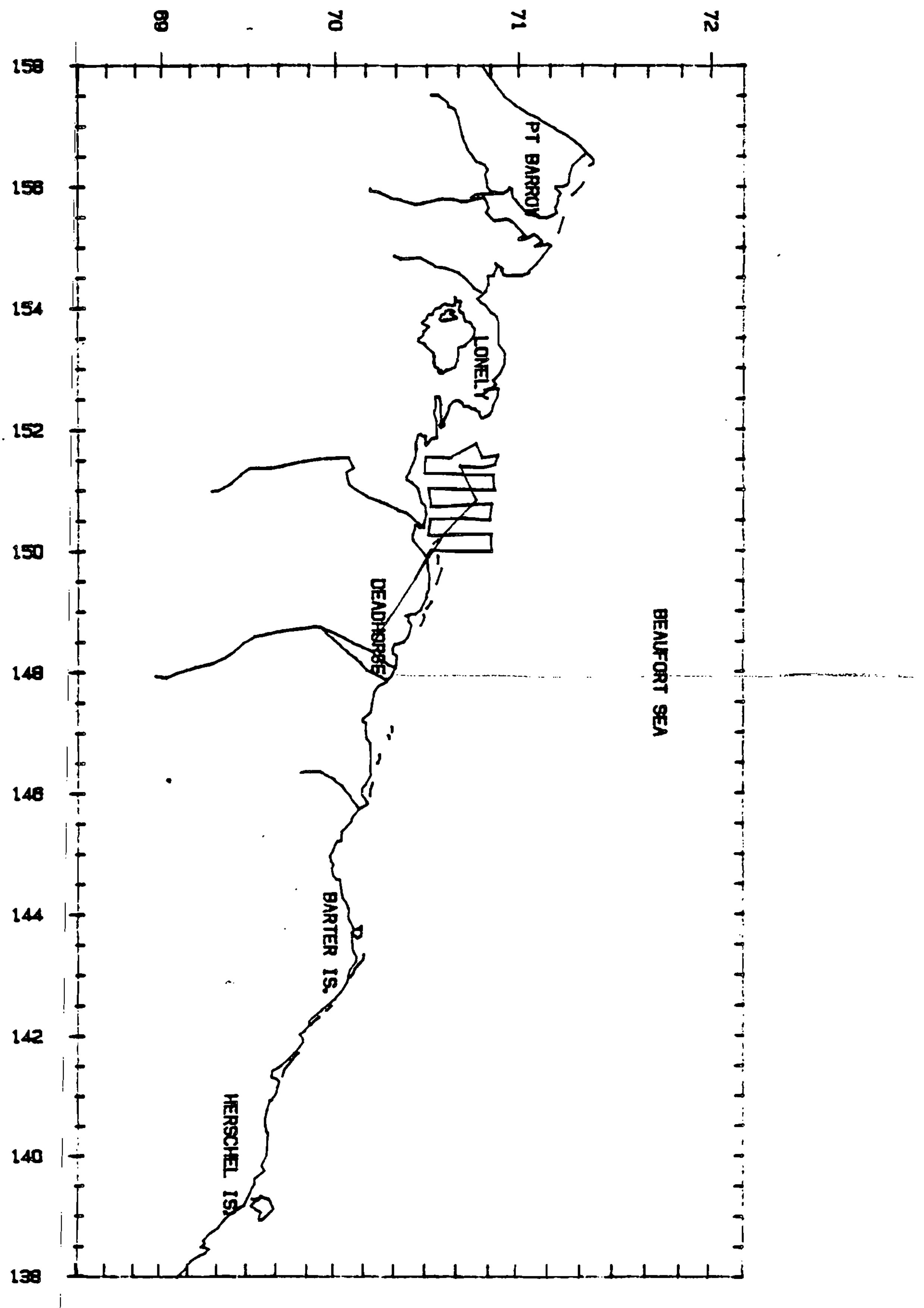
Flight 9: 29 August 1983

This flight was a grid survey of the Krystal Sea at 70°40.2'N, 151°26.0'W. Ice was absent in the southern half of the grid and 3/10 to 4/10 broken floe in the northern half. Sea state was Beaufort 1. Weather was overcast with unlimited visibility. No bowheads were sighted. Unidentified pinnipeds were the only animals seen.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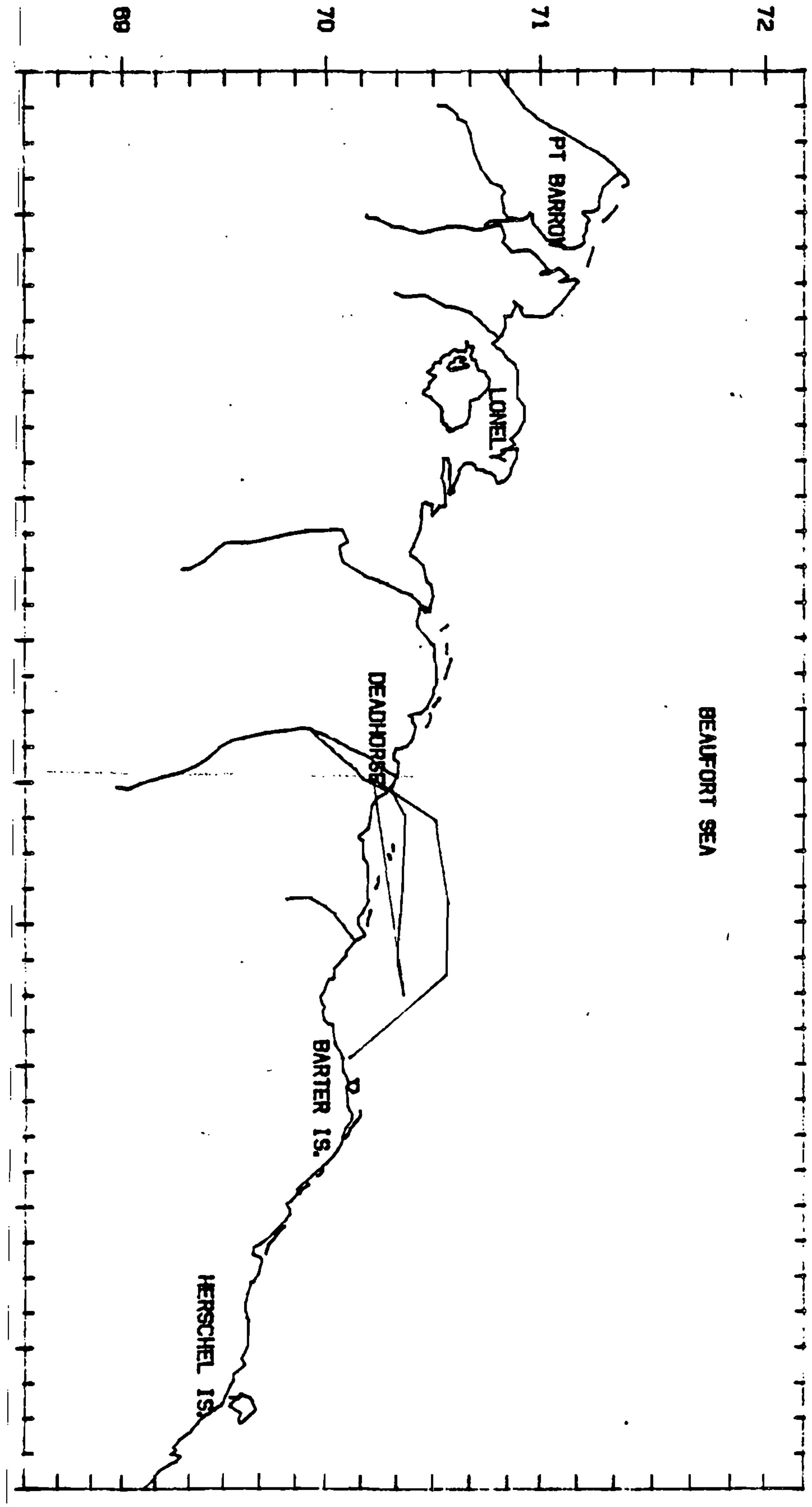
PT BARROW
LONELY
DEADHORSE
BEAUFORT SEA
BARTER IS.
HERSCHEL IS.

Flight 10: 30 August 1983

This flight was a search survey eastward from Deadhorse, aborted due to heavy fog and poor visibility. A second flight was attempted but aborted due to aircraft mechanical problems.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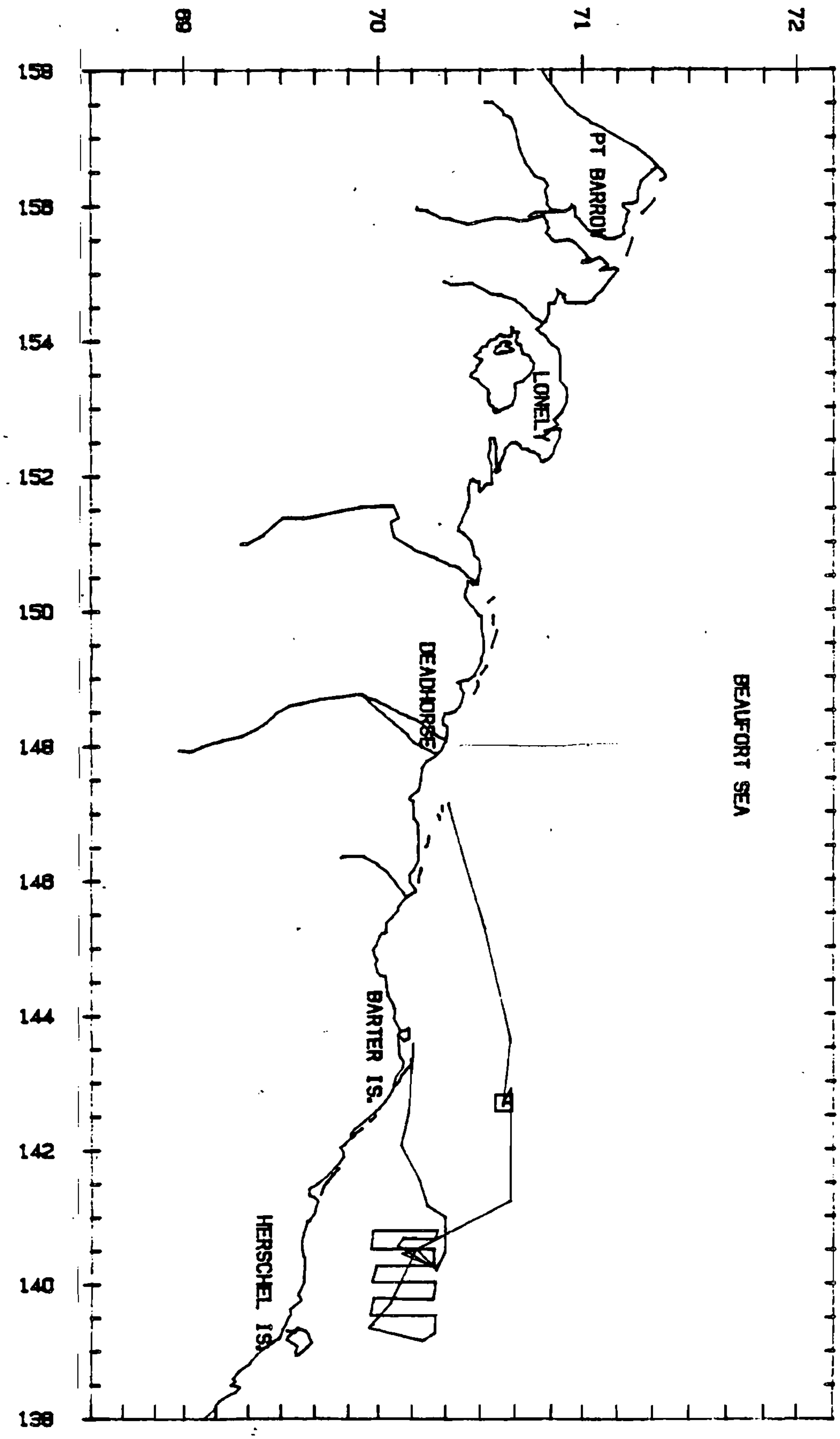
BEAUFORT SEA
BARTER IS.
HERSCHEL IS.

Flight 11: 31 August 1983

This flight was a grid survey of the GSI Alaskan at 70°07.0'N, 140°41.0'W, and a search survey westward along the open-water leads at 70°40'N. Ice conditions in the survey area ranged from 0/10 to 5/10 broken floe, and the sea state was Beaufort 0 to 1. Weather was generally clear with unlimited visibility. One bowhead was sighted at 1455 hr at 70°36.4'N, 142°41.7'W in a lead surrounded by 5/10 broken floe ice, approximately 95 km from the nearest seismic vessel. The bowhead was small to medium-size. It was light gray or mottled, and it had no obvious white markings on the chin or tail peduncle. The whale tail-slapped, spyhopped and blew underwater. It was observed for only a few minutes before it dove under a large pan of grease ice and disappeared. A cow-calf belukha pair was sighted at 70°36.4'N, 142°39.1'W at 1459 hr in the same lead as the bowhead. They were swimming slowly and heading 150°(M). The calf occasionally swam under the cow. Both belukhas eventually dove under grease ice and were not resighted. Unidentified pinnipeds were also seen. Seismic sounds from two geophysical vessels were recorded.

T#/C#	LAT	LONG	TIME	BEH	HDG	ICE	SS	DEPTH	SEISMIC	DIST
1/0	70°36.4'	142°41.7'	1455	MI	-	5	0	457	NO	



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BEAUFORT SEA
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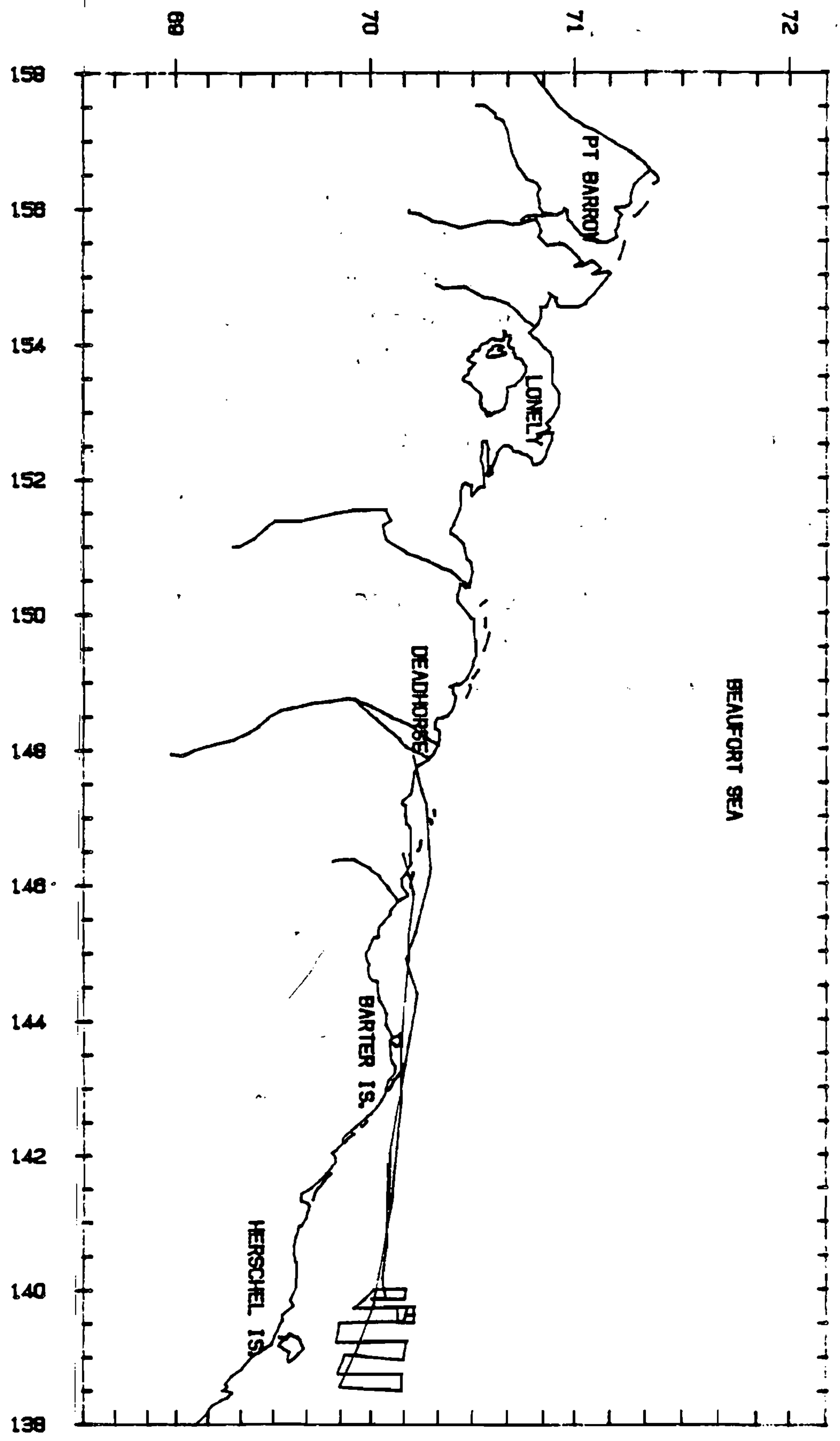
Flight 12: 2 September 1983

This flight was a search survey along the 20 m isobath east from Deadhorse to the Western Aleutian at 70°00.2'N, 139°51.9'W, where a grid survey was begun. Ice conditions in the area surveyed varied from 0/10 in the southeastern parts of the grid to 9/10 in the northern parts. Sea state ranged from Beaufort 0 to 2. Weather was generally clear with unlimited visibility. One bowhead was sighted within the grid at 1122 hr at 70°10.3'N, 139°37.6'W, approximately 21.8 km northeast of the Western Aleutian, which was shooting at the time. The bowhead appeared to be resting at the surface, with a heading of 120°(M), when initially sighted. There was no obvious response to the aircraft, which maintained 370 m of altitude. All four geophysical vessels in the area, the Aleutian, the Alaskan, the Polaris, and the Vetter were called immediately on the marine band radio. The Aleutian and the Vetter responded, and they were informed of the whale's position. Ringed seals and unidentified pinnipeds were also seen.

T#/C#	LAT	LONG	TIME	BEH	HDG	ICE	SS	DEPTH	SEISMIC	DIST
1/0	70°10.3'	139°37.6'	1122	MI	120	3	1	254	YES	21.8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BARTER IS.
HERSCHEL IS.
BEAUFORT SEA
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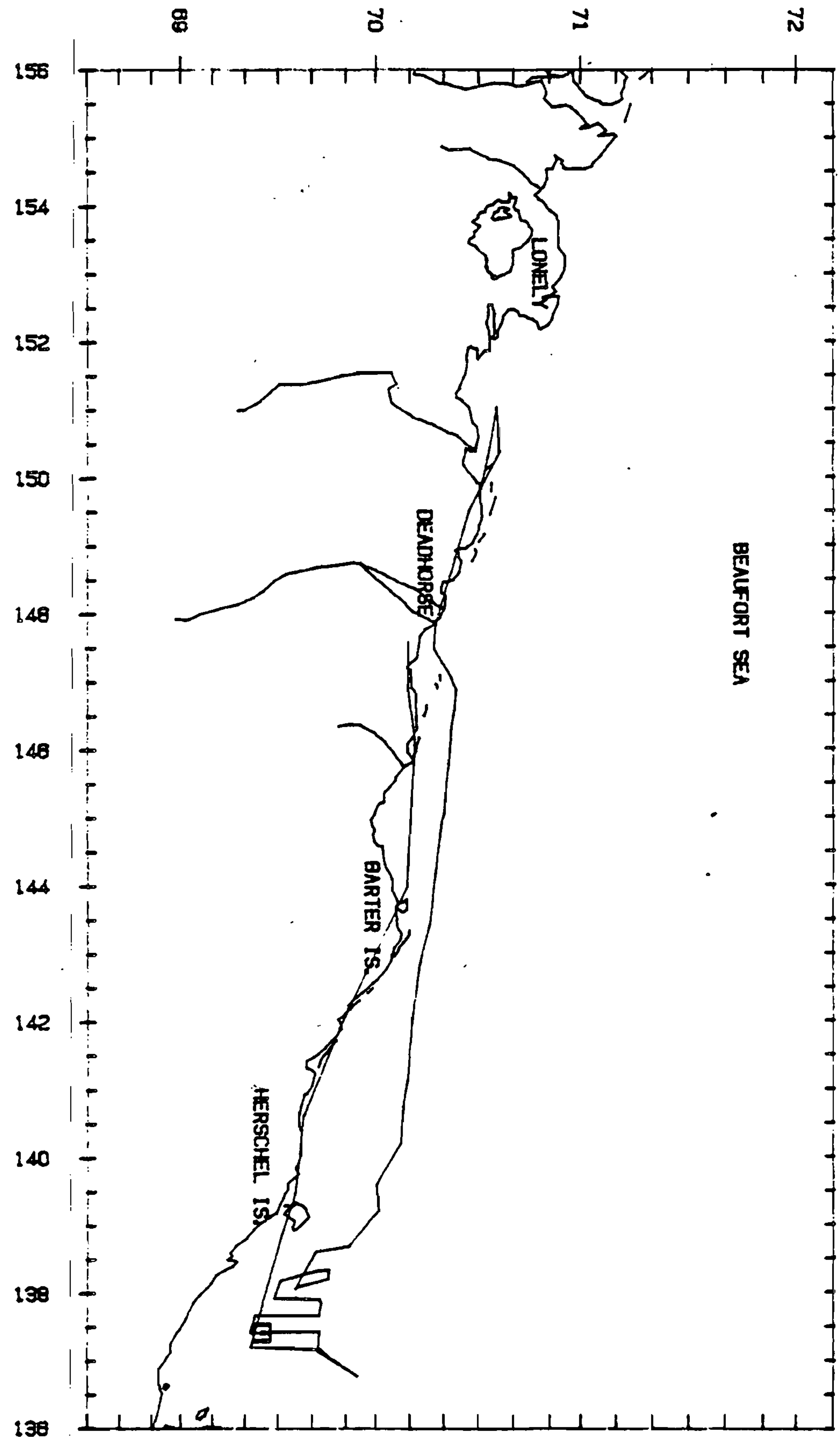
Flight 13: 3 September 1983

This flight was originally intended to be a grid survey of the Krystal Sea in Harrison Bay at 70°38.3'N, 151°23.7'W, but heavy fog conditions prevented this. Instead a search survey was flown along the 20 m isobath east from Deadhorse to the Edward O. Vetter at 69°35.0'N, 138°03.9'W, where a grid survey was begun. Ice conditions in the grid survey area were generally 0/10 to 2/10 broken floe, with sea state Beaufort 1 to 2. Ice along the 20 m isobath ranged from 4/10 to 9/10 broken floe. Weather was overcast with unlimited visibility. Two bowheads, one of them breaching (three times in rapid succession), were sighted at 69°25.0'N, 137°25.0'W, approximately 26.5 km southeast of the Vetter. The Vetter was shooting during the period of observation (20 min). The whales were within 1/2 km of each other and both were heading west. Ringed and bearded seals, unidentified pinnipeds, and a polar bear were also seen. Bowhead and seismic sounds were recorded.

T#/C#	LAT	LONG	TIME	BEH	HDG	ICE	SS	DEPTH	SEISMIC	DIST
1/0	69°24.8'	137°24.4'	1459	BR	300	2	1	37	YES	26.5
1/0	69°25.0'	137°25.9'	1502	TR	300	2	1	37	YES	26.5



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LONELY
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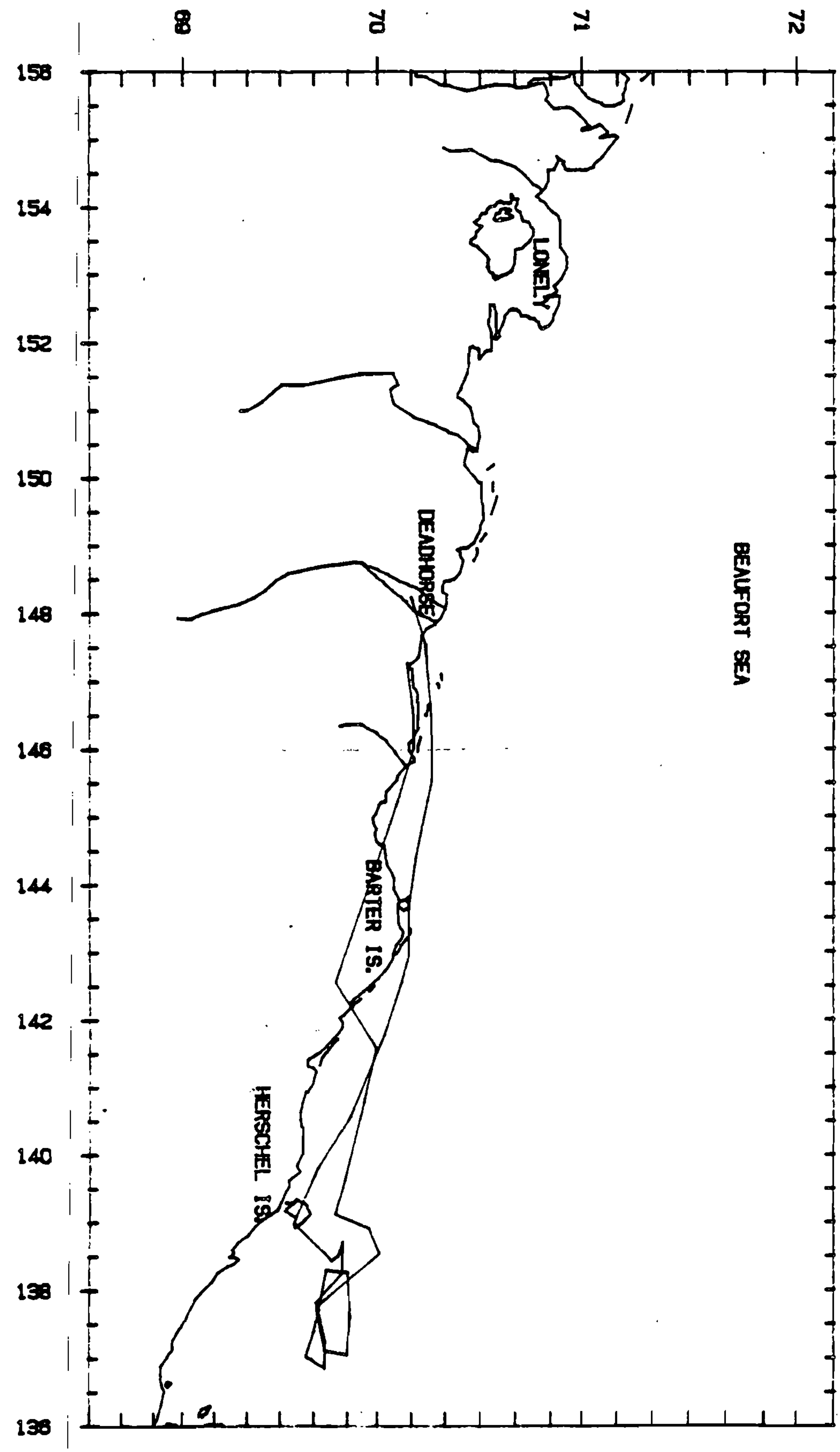
BEAUFORT SEA
BARTER IS.
HERSCHEL IS.

Flight 14: 4 September 1983

This flight was a search survey around three geophysical vessels in the area of 69°45'N, 138°W. Ice conditions in the area surveyed varied from 0/10 to 5/10 broken floe. Along the 20 m isobath, 9/10 broken ice had been blown in from the north. Sea state was Beaufort 0 in heavy ice areas and Beaufort 3 in open water. Weather was overcast with unlimited visibility. No bowheads were sighted. A solitary belukha was seen at 1509 hr at 69°46.9'N, 138°31.2'W, and a group of six belukhas heading 120°(M) was seen at 1602 hrs at 69°39.1'N, 136°58.9'W. A sonobuoy was dropped and faint seismic sounds were heard. These probably did not originate from any of the three vessels in the immediate area.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LONELY
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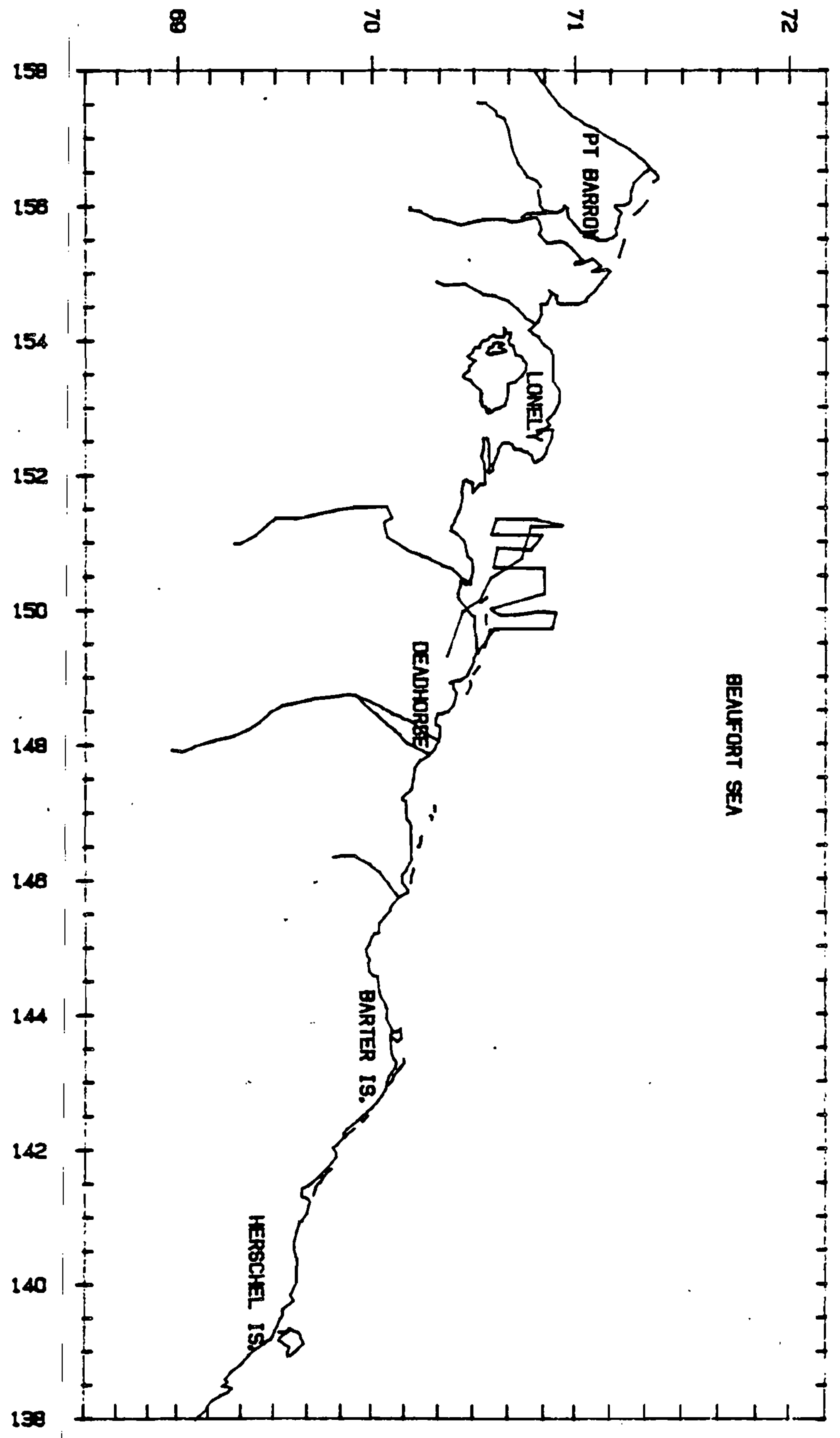
BEAUFORT SEA
BARTER IS.
HERSCHEL IS.

Flight 15: 5 September 1983

This flight was a grid survey of the Krystal Sea at 70°46.1'N, 151°14.9'W. Ice conditions in the survey area were mostly 0/10 to 1/10 broken floe; the northeast corner of the grid was covered with 9/10 ice. Sea state was Beaufort 3. Weather was overcast with unlimited visibility. No bowheads were sighted. Belukhas and an unidentified pinniped were the only marine mammals seen. The belukhas were seen in two distinct groups, one of eight individuals at 70°47.5'N, 149°58.9'W and the other of 10 individuals at 70°49.6'N, 149°59.2'W. Seismic sounds from a geophysical vessel were recorded.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PT BARROW
LONELY
DEADHORSE
BEAUFORT SEA
BARTER IS.
HERSCHEL IS.

Flight 16: 6 September 1983

This flight was a search survey north of Barter Island to the 71°N latitude line, east to 136°40'W, south to 69°45'N and returning to Deadhorse along the shoreline. Ice conditions were 9/10 broken floe along 71°N, 0/10 to the east at 136°30'W. Sea state ranged from Beaufort 0 to 2. Weather was generally overcast with unlimited visibility.

Two small bowheads were sighted in 4/10 broken floe ice at 70°59'N, 143°35'W. They appeared to be milling, possibly feeding, along the edge of a large ice pan. The whales were closely associated, separated from each other by as little as one whale length. Our observation period was 24 minutes. The nearest active geophysical vessel was at least 170 km away (to the east).

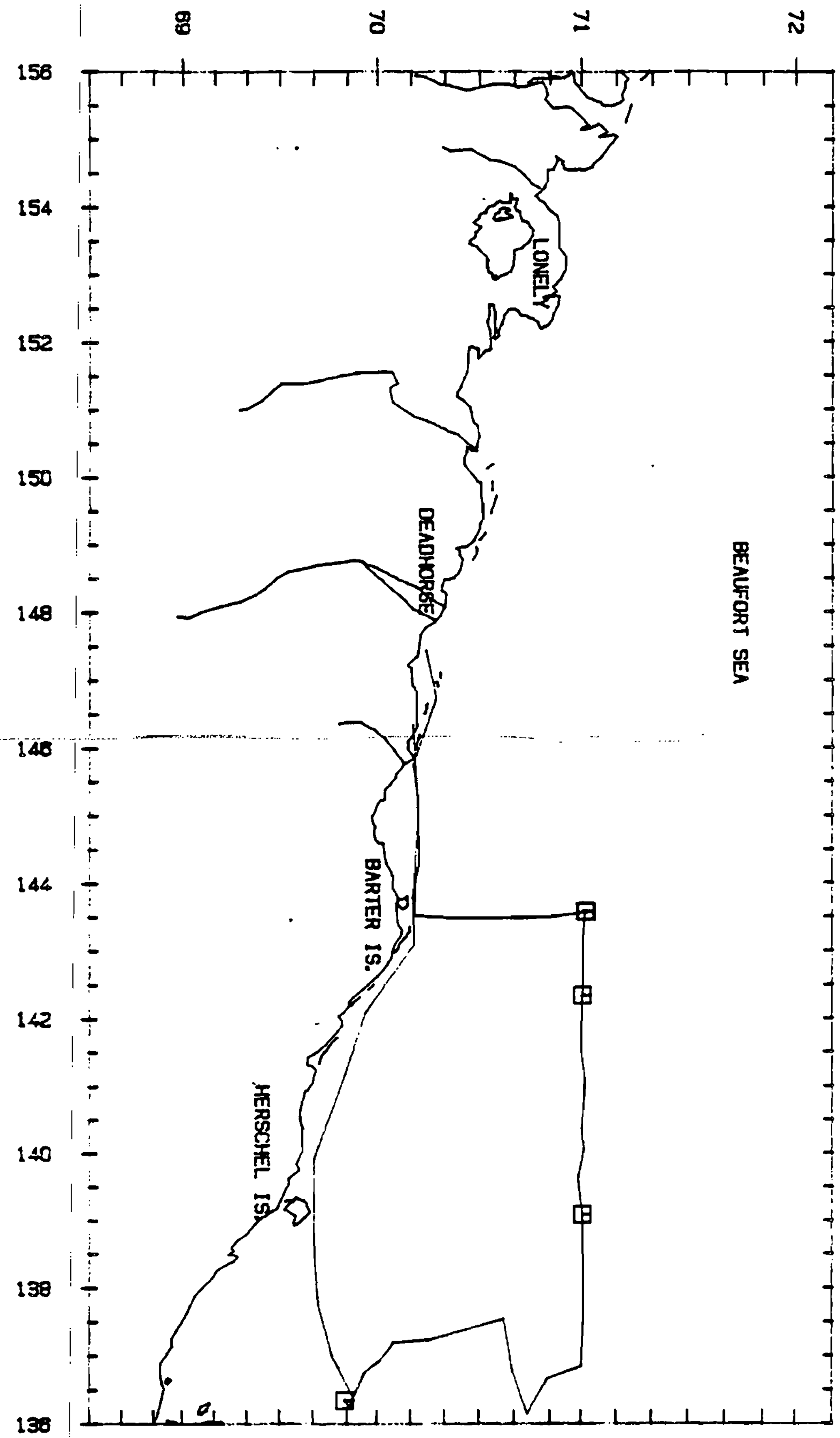
A large splash seen at 71°N, 142°20'W was considered a bowhead, but the animal itself was not sighted.

A very large bowhead sighted at 71°N, 139°04'W was swimming southwest at a fast rate.

A group of feeding bowheads was detected in Mackenzie Bay by observation of a series of mud plumes in the water column. As many as 8-10 of these plumes could be seen at a given time. At least 5 bowheads, separated by distances of 50-200 m, were confirmed to be in the area. One was a light gray calf. Mud was streaming from the mouth of one individual as it rested near the surface. A large number of birds were present. Water color differences - blue to green, plus the orange to golden mud plumes - were noted. No seismic sounds were heard, but 4-5 small vessels and an island with industrial activity on and near it were seen less than 10 km to the east. Our observations lasted only 15 min., after which it was necessary to return to Alaska for fuel.

Approximately twenty scattered belukhas were seen at 1259 hr at 71°00.3'N, 142°39.4'W. They appeared to be milling, and one cow-calf pair was included in the group. Unidentified pinnipeds were also seen.

T#/C#	LAT	LONG	TIME	BEH	HDG	ICE	SS	DEPTH	SEISMIC	DIST
1/0	70°59.9'	143°34.0'	1226	MI	210	5	0	1280	NO	-
1/0	70°59.5'	143°34.7'	1245	MI	-	4	1	1280	NO	-
1/0	71°00.2'	142°20.0'	1308	TR	-	5	1	1884	NO	-
1/0	71°00.3'	139°04.9'	1335	TR	210	3	1	1939	NO	-
5/1	69°49.3'	136°20.5'	1453	FE	-	0	2	16	NO	-



LONELY
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BARTER IS.
HERSCHEL IS.
BEAUFORT SEA
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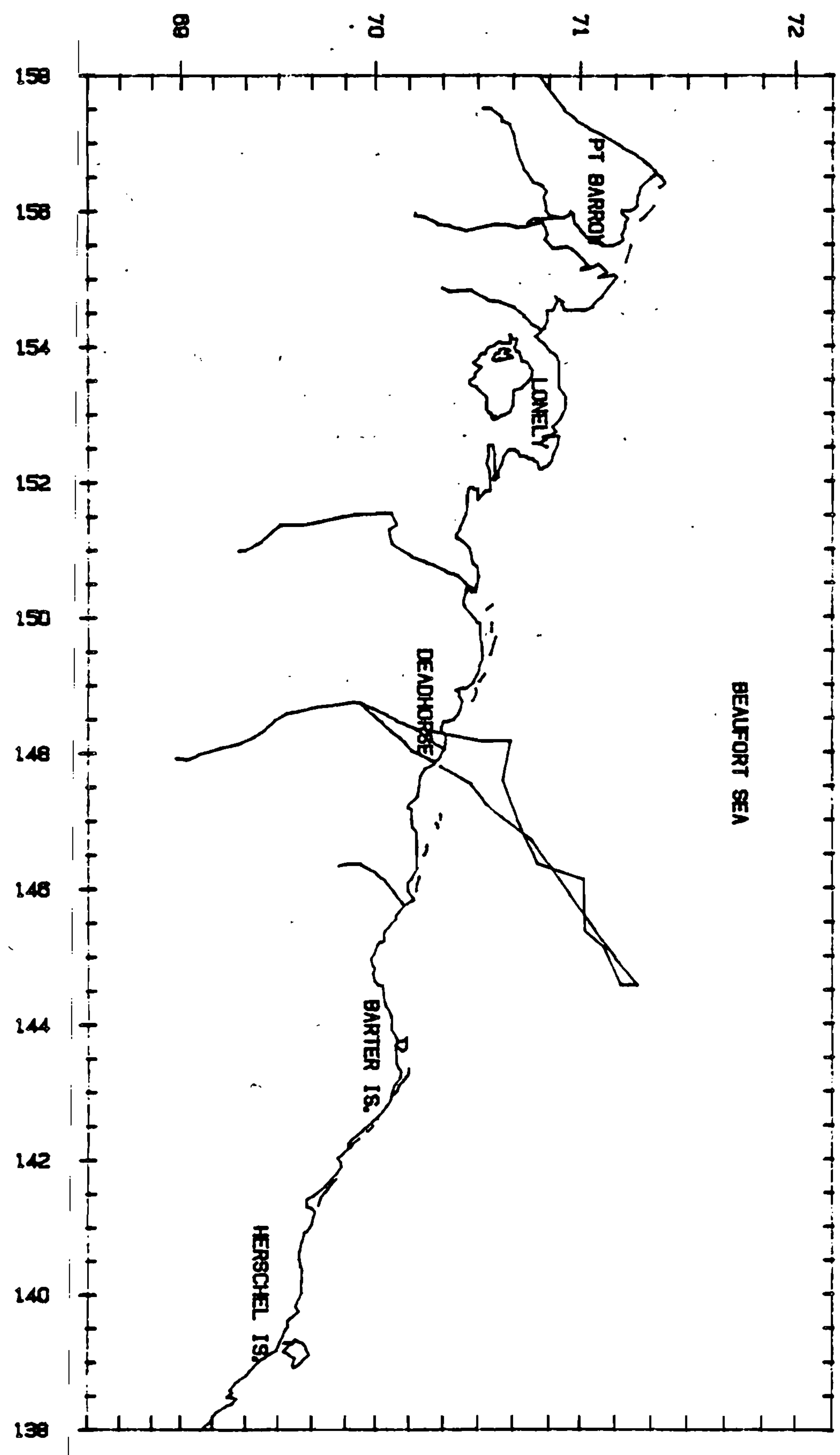
Flight 17: 7 September 1983

This flight was a search survey northeast from Deadhorse to 71°11'N, 144°35'W. No grid survey was attempted due to heavy fog and poor visibility in all areas. Ice conditions were 9/10 broken floe nearshore and out to 70°40'N; beyond that, 6/10 broken floe and Beaufort 3 sea state. No bowheads were sighted. One unidentified pinniped was seen.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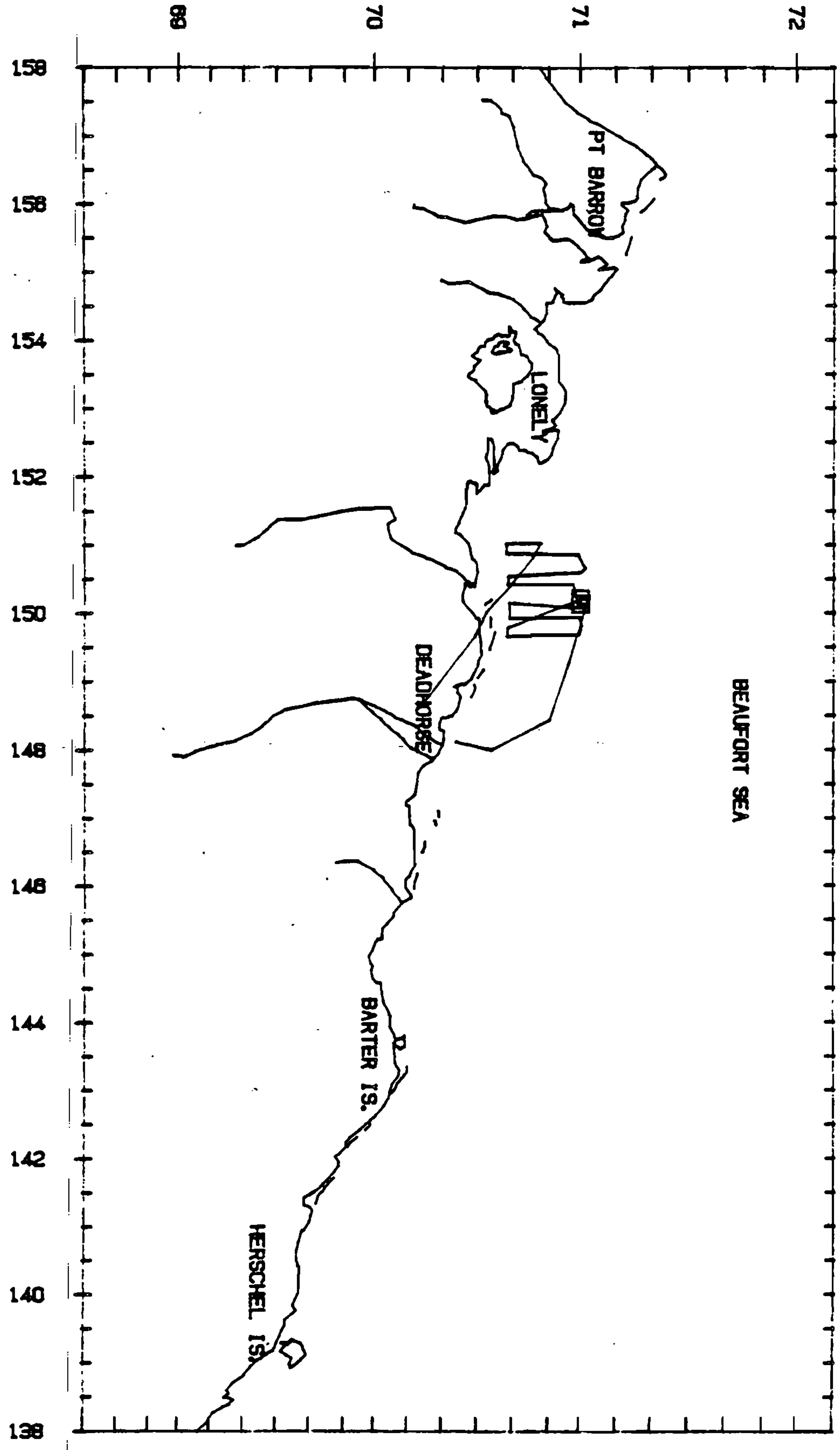
PT BARROW
LONELY
DEADHORSE
BEAUFORT SEA
BARTER IS.
HERSCHEL IS.

Flight 18: 8 September 1983

This flight was a grid survey of the Krystal Sea in Harrison Bay at 70°47.6'N, 151°02.1'W. Ice conditions in most of the survey area were 0/10, with a sea state of Beaufort 2, but the northern perimeter of the grid was covered by 3/10 to 5/10 broken floe. Weather varied from foggy to overcast, and visibility ranged from 1 km to unlimited. One bowhead was sighted at 1339 hr at 70°58.5'N, 150°08.4'W, approximately 41.6 km from the Krystal Sea. The vessel was not shooting at the time. An attempt was nevertheless made to notify the vessel of the whale's position. Upon completion of the grid, the whale was resighted at 1428 hr at 70°58.4'N, 150°12.8'W and observed for 53 min during which time the Krystal Sea was shooting. The whale's heading was consistently northwest; we estimated the net distance traveled as 6.8 km in 102 min, for a mean rate of 4.0 km/h. By 1515 hr, visibility had deteriorated so much that we were forced to terminate our observations of the bowhead. Unidentified pinnipeds were also seen.

T#/C#	LAT	LONG	TIME	BEH	HDG	ICE	SS	DEPTH	SEISMIC	DIST
1/0*	70°58.5'	150°08.4'	1339	TR	300	3	1	22	NO	-
1/0*	70°58.4'	150°12.8'	1428	TR	300	3	1	22	YES	41

*same whale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PT BARROW
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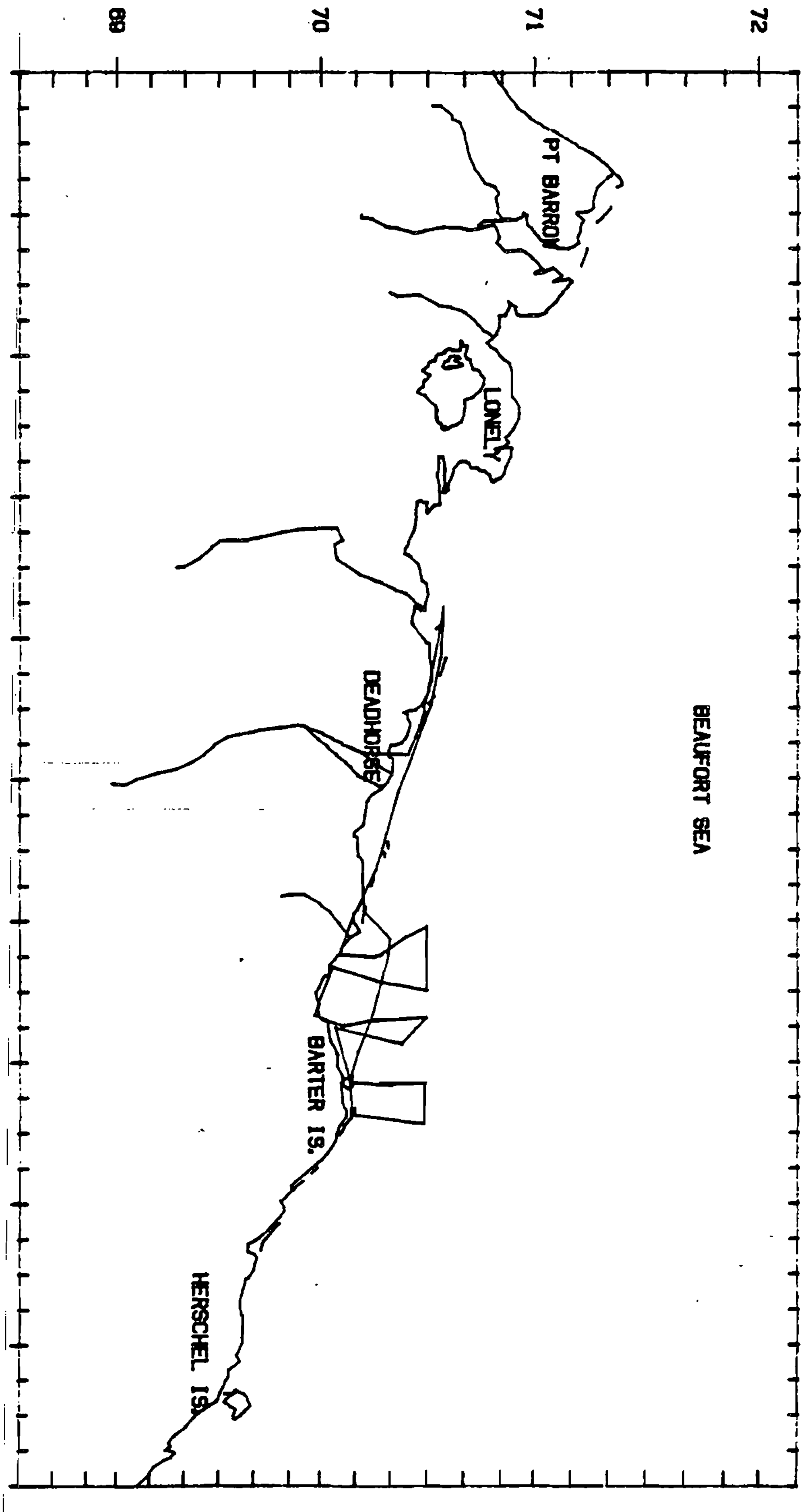
BEAUFORT SEA
BARTER IS.
HERSCHEL IS.

Flight 19: 9 September 1983

This flight was a transect survey of Block 4 in support of the endangered whale study. A grid survey of a geophysical vessel was not attempted due to poor weather conditions and a lack of vessel activity. Ice conditions in Block 4 were mostly 1/10 broken floe in the southern half and 9/10 broken floe in the northern half. Sea state was Beaufort 0 to 2. Weather was overcast with unlimited visibility. No bowheads were sighted. A bearded seal and an unidentified pinniped were the only marine mammals seen.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PT BARROW
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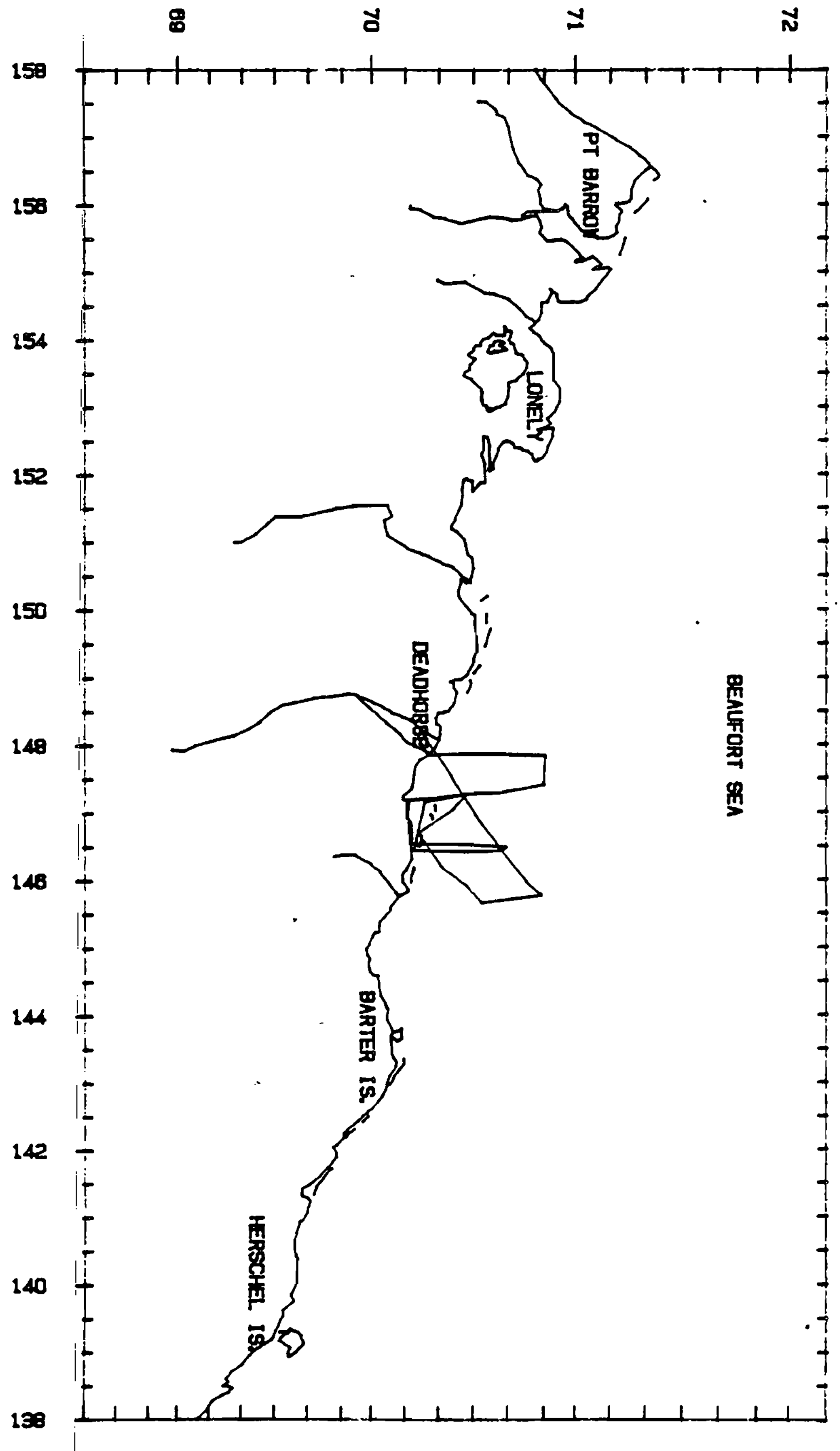
BARTER IS.
HERSCHEL IS.
BEAUFORT SEA

Flight 20: 10 September 1983

This flight was a transect survey of the eastern half of Block 1 in support of the endangered whale study. A grid survey of a geophysical vessel was not attempted due to poor weather conditions and a lack of vessel activity. Ice conditions in the survey area were generally 9/10 broken floe with a sea state of Beaufort 0 in the northern half of Block 1, and 0/10 ice with a sea state of Beaufort 1 in the southern half of Block 1. Weather was overcast with unlimited visibility. No bowheads were sighted. Unidentified pinnipeds and a bearded seal were seen.



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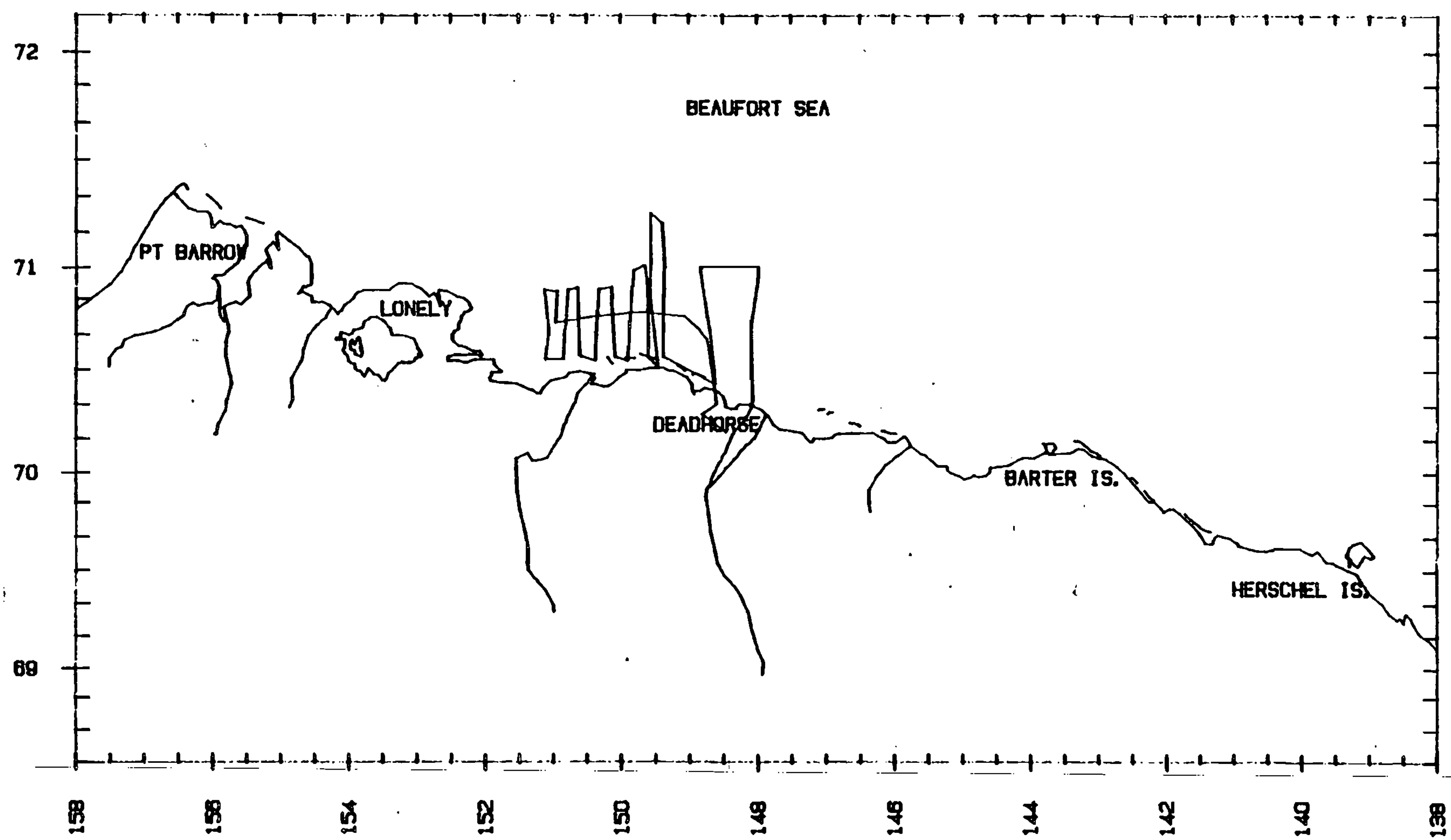
Flight 21: 10 September 1983

This flight was a grid survey of the Krystal Sea in Harrison Bay at 70°43.5'N, 150°57.8'W, followed by a transect survey of the western half of Block 1. Ice conditions in the grid survey area and the southern half of Block 1 were generally 0/10 to 1/10 broken floe with a sea state of Beaufort 1, and 8/10 to 9/10 broken floe in the northern half of Block 1. Weather was clear to overcast with unlimited visibility. No bowheads were sighted. A polar bear and unidentified pinnipeds were seen. Seismic sounds were recorded from one geophysical vessel.



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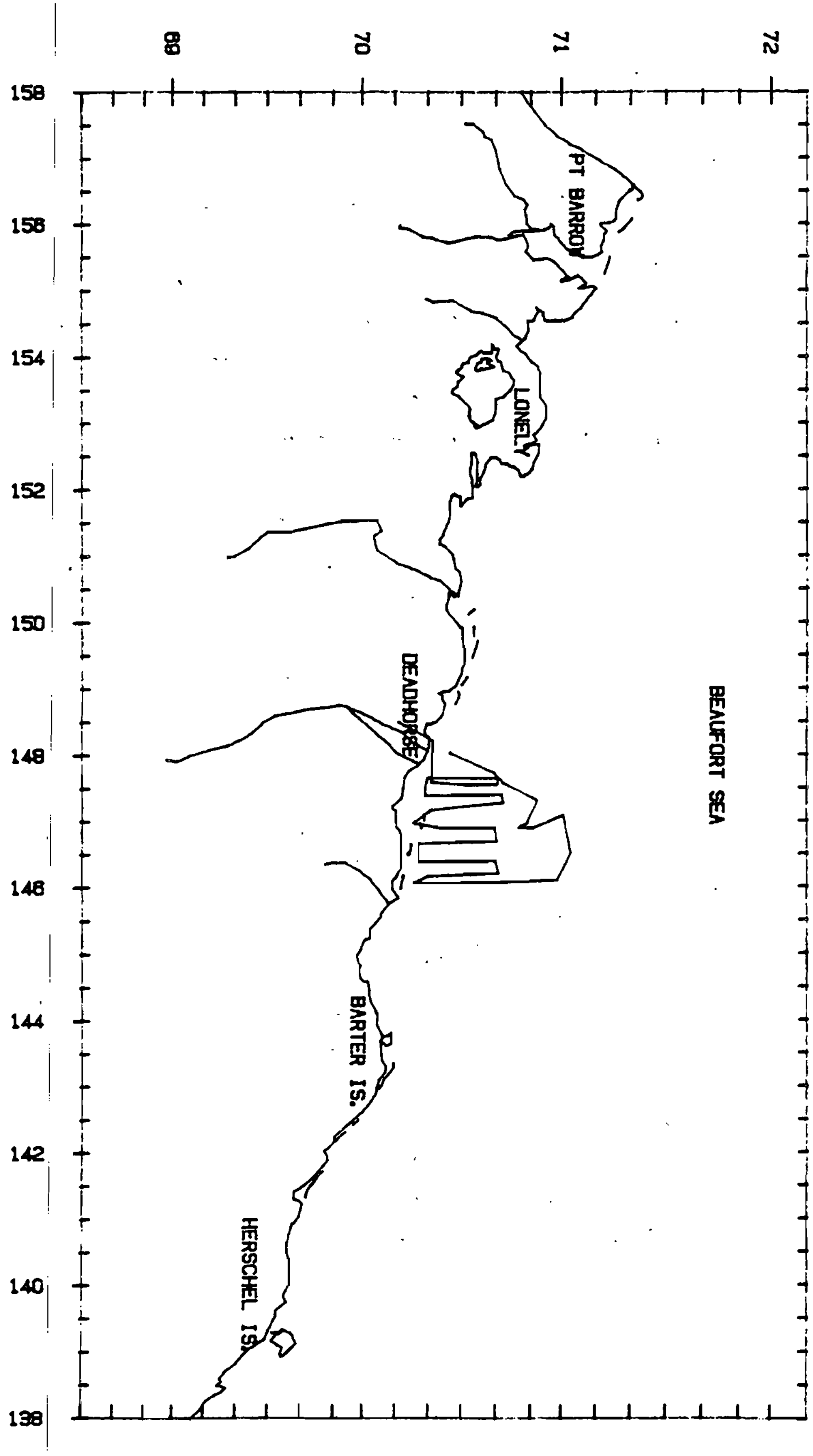
Flight 22: 12 September 1983

This flight was a grid survey of the Edward O. Vetter at 70°30.7'N, 147°33.0'W. Ice conditions in the survey area were 0/10 in all but the northern portions of the grid, where coverage was 9/10 broken floe. Sea state was Beaufort 0 to 1. Weather was partly cloudy to overcast with unlimited visibility. No bowheads were sighted. Unidentified pinnipeds were the only marine mammals seen.



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PT BARROW
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BARTER IS.
HERSCHEL IS.
BEAUFORT SEA

Flight 23: 12 September

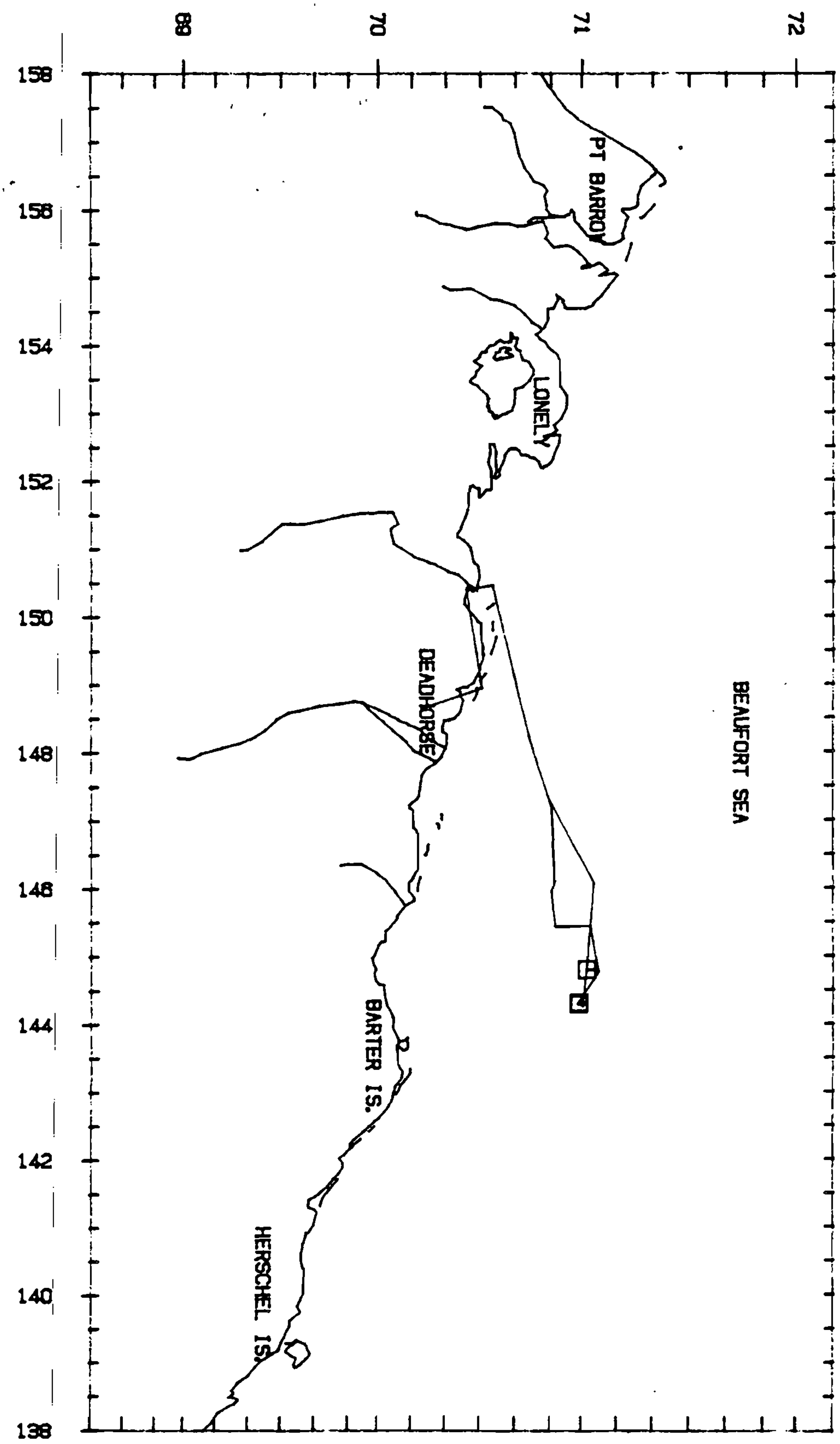
This flight was intended to be a grid survey of the Krystal Sea, but poor weather conditions forced us to abort the grid survey. Instead, we conducted a search survey along the 71°N latitude line. Ice conditions in the area of the sightings were 7/10 broken floe, and sea state was Beaufort 0. Weather was clear with unlimited visibility.

Four bowheads, including one calf, were sighted at 70°57.8'N, 144°19'W, heading north. Two more bowheads were sighted in the same area. The larger of these two breached 13 times in succession, slapped the surface with its flukes and flippers, and lunged. The smaller individual, traveling about 300 m behind the other whale, also breached at least once. After losing these two whales in the ice, we observed eight more bowheads at 70°59.9'N, 144°48.3'W, swimming west. A solitary individual was in the lead, followed by another individual at a distance of about 90 m. After the first whale dove under an ice sheet, the second breached four times, tail-lobbed, and dove under the same ice sheet. The other six whales were in two groups of three, separated by about 90 m. The first group included a small calf; the second, a somewhat larger calf. It was surmised that at least some of the eight whales could have been the same whales that we had seen earlier in the flight. Quantitative data on behavior at and near the surface were collected during the two hrs of observation.

Approximately 150 belukhas were seen at 1503 hr at 71°02.2'N, 145°27.2'W in a lead surrounded by 9/10 broken floe ice. All were consistently heading 210°(M). Many light gray belukha calves (approx. 20% of the total whales in this group) were seen in close association with the adults. An unidentified pinniped was also seen. Bowhead and belukha sounds were recorded; no seismic sounds were heard.

T#/C#	LAT	LONG	TIME	BEH	HDG	ICE	SS	DEPTH	SEISMIC	DIST
4/1*	70°57.8'	144°19.0'	1519	TR	330	6	0	549	NO	-
2/0	70°57.6'	144°17.7'	1523	BR	240	6	0	549	NO	-
8/2*	70°59.9'	144°48.3'	1734	TR	240	7	0	915	NO	-

*duplicate sighting suspected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PT BARROW
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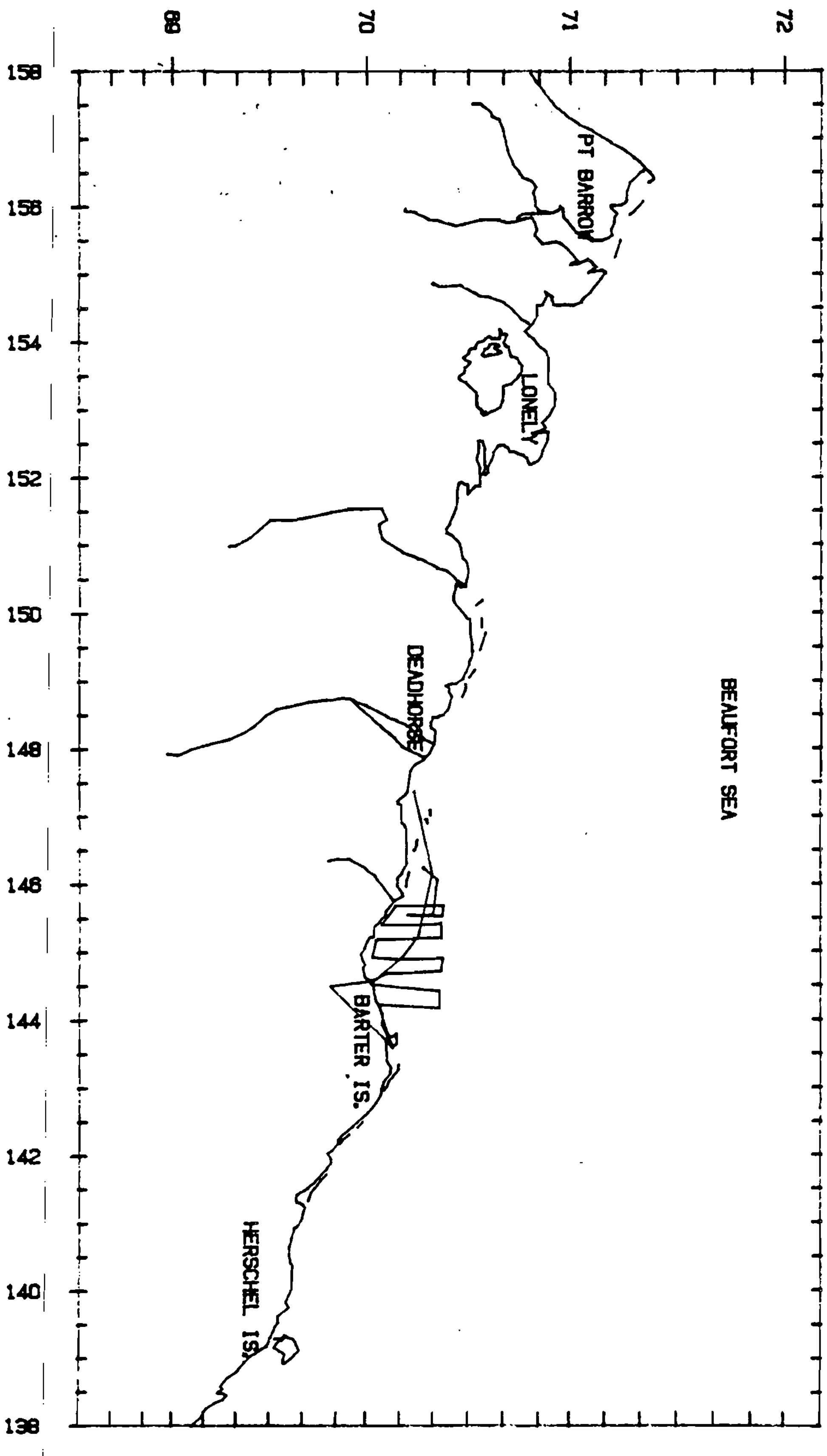
BARTER IS.
HERSCHEL IS.

Flight 24: 14 September 1983

This flight was a grid survey of the Western Aleutian at 70°13.2'N, 145°33.4'W. Ice conditions in the survey area were 1/10 to 3/10 broken floe with a sea state of Beaufort 1. Weather was overcast with unlimited visibility. No bowheads were sighted. Unidentified pinnipeds were the only marine mammals seen.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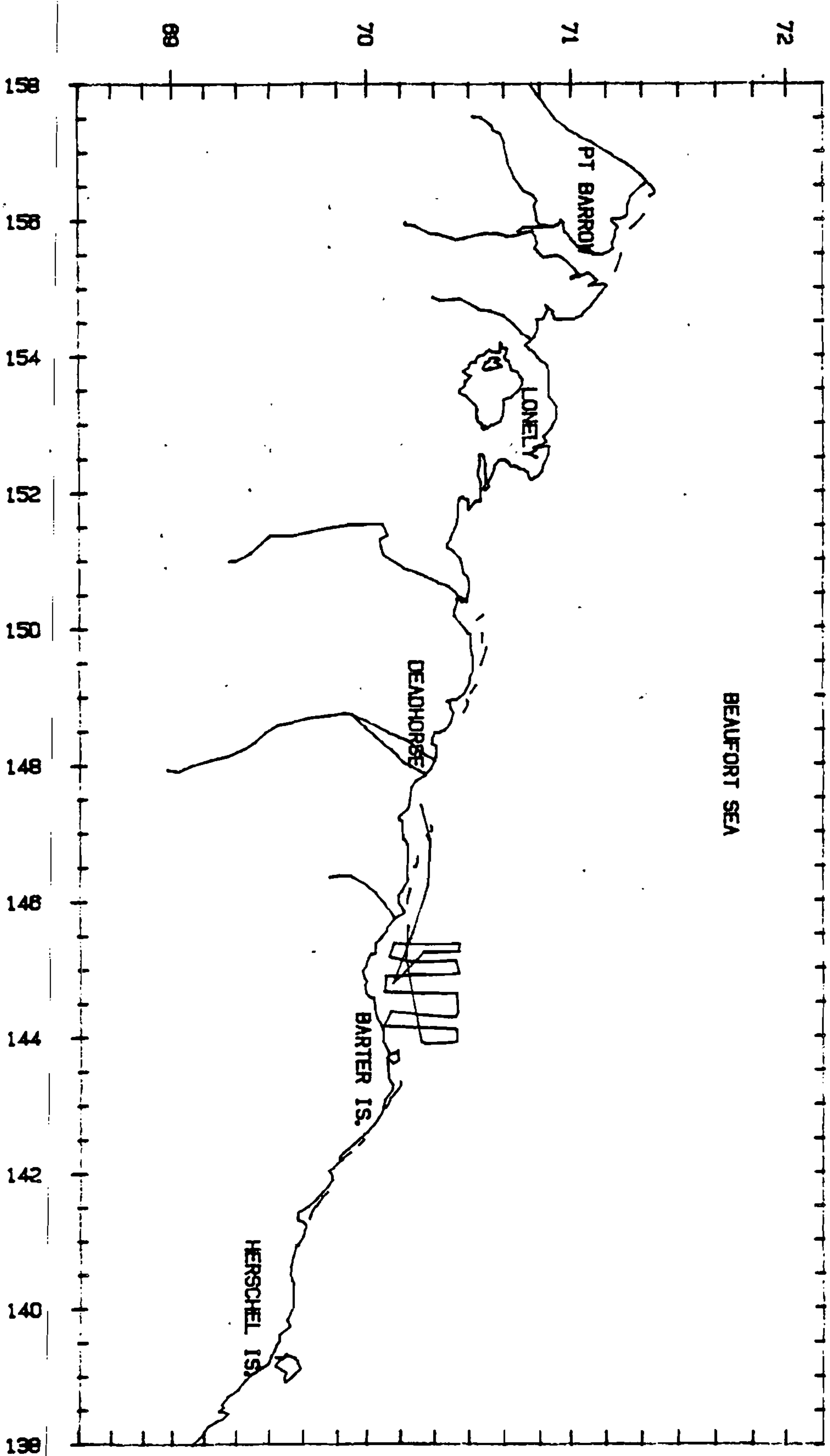
BEAUFORT SEA
BARTER IS.
HERSCHEL IS.

Flight 25: 15 September 1983

This flight was a grid survey of the Western Polaris at 70°15.7'N, 145°16.3'W. Ice conditions in the area surveyed were generally 2/10 broken floe in all but the northernmost sections of the grid. Sea state was Beaufort 0 to 1. Weather was overcast with unlimited visibility. No bowheads were sighted. Unidentified pinnipeds and a bearded seal were seen. Seismic sounds from one geophysical vessel were recorded.



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PT BARROW
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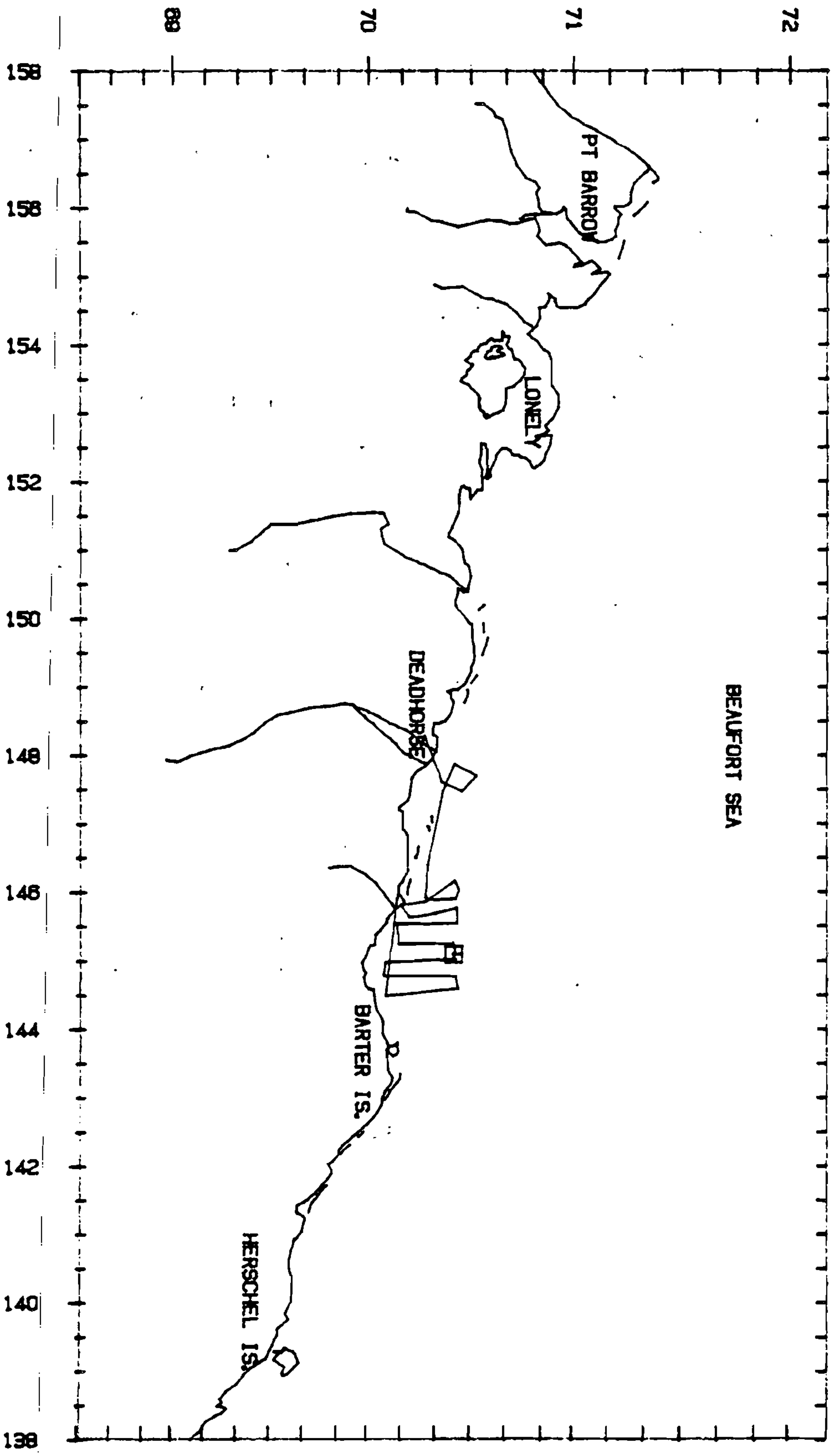
BARTER IS.
HERSCHEL IS.

Flight 26: 15 September 1983

This flight was a grid survey of the GSI Alaskan at 70°26.2'N, 147°29.4'W, and the Western Aleutian at 70°15.6'N, 145°55.9'W. Ice conditions in the survey area were generally 2/10 broken floe in the southern half of the grid and 9/10 in the northern half. Sea state was Beaufort 0 to 1. Weather was overcast with visibility varying from less than 1 km to unlimited.

One bowhead was sighted within the grid at 1616 at 70°23.9'N, 145°06.3'W, approximately 34 km northeast of the Aleutian, which was shooting. The whale was in ice of 8/10 coverage, swimming slowly to the northwest. A sonobuoy dropped near the whale revealed faint seismic pulses which we later determined were from the Aleutian. Because of the heavy ice near the whale, the late time of day, and the whale's considerable distance from the Aleutian, the whale was left after a short (<15 min) period of observation and the grid was completed. Unidentified pinnipeds were also seen. The sonobuoy dropped during flight 25 was monitored, and seismic sounds were recorded.

T#/C#	LAT	LONG	TIME	BEH	HDG	ICE	SS	DEPTH	SEISMIC	DIST
1/0	70°23.9'	145°06.3'	1616	TR	240	9	0	38	YES	34



PT BARROW
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BEAUFORT SEA
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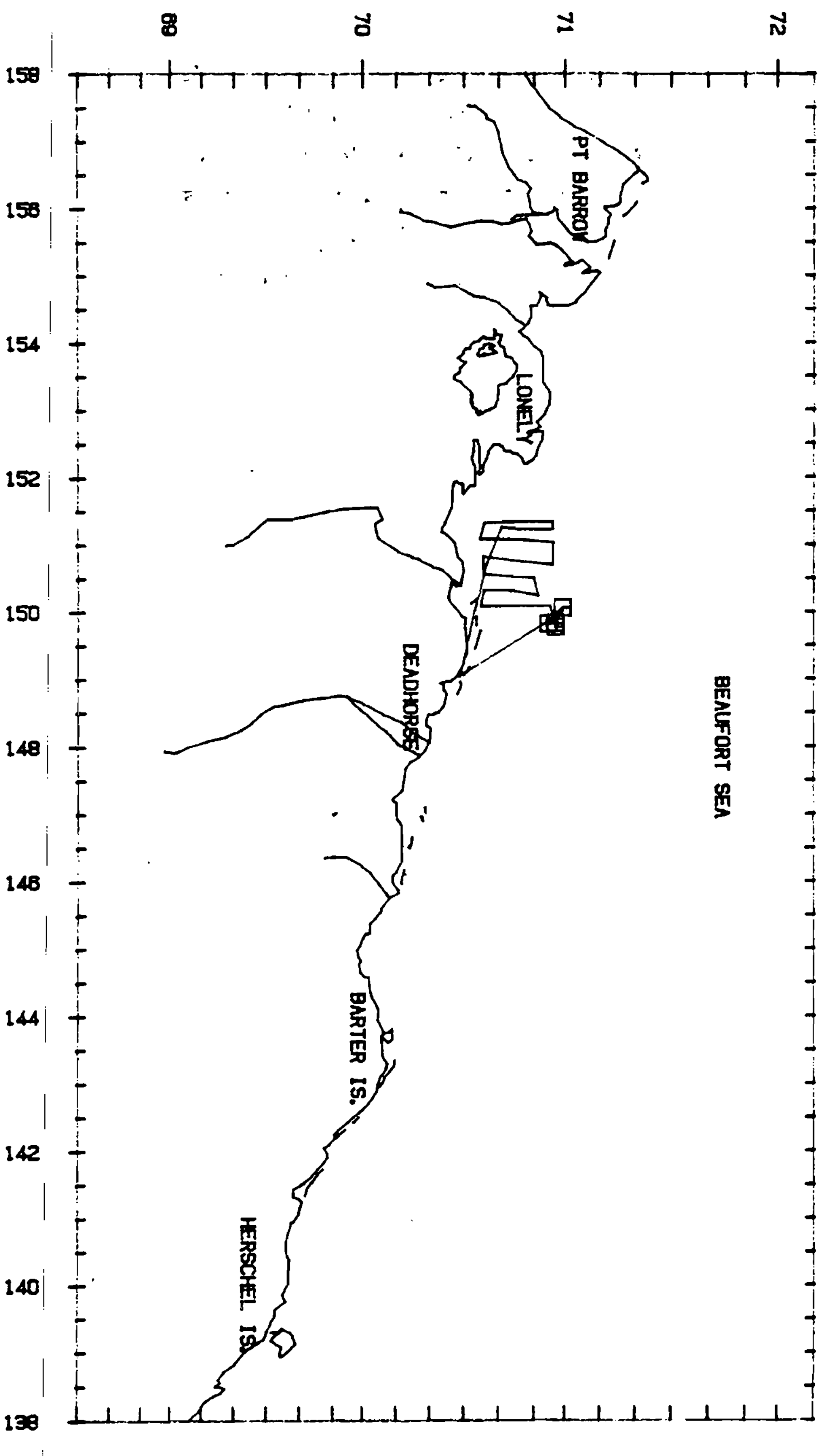
Flight 27: 16 September 1983

This flight was a grid survey of the Krystal Sea at 70°45.0'N, 151°14.2'W. Ice conditions in the survey area were 0/10 with sea state Béaufort 1 in all but the northeast corner of the grid, where the coverage was 3/10 to 4/10 broken floe and Beaufort 0. Patchy fog and rapidly decreasing visibility eventually forced us to terminate the flight.

Approximately 10 bowheads, all heading west, were sighted within the grid at 1435 hr at 70°55'N, 149°49'W, approximately 57 km northeast of the Krystal Sea, which was shooting. These whales were all inside a five km^2 area near the outer edge of the nearshore corridor of open water. Three of them were closely associated with one another. The Krystal Sea was notified at 1447 hr of the whales' position, heading, and behavior and was asked to pass this information on to our colleagues in Deadhorse. However, the opportunity for an experimental disturbance trial was lost because of the distance between the whales and the Krystal Sea and because visibility was decreasing rapidly. By 1605 hr visibility was close to zero in the vicinity of the whales.

One belukha was seen at 1539 hr at 70°56.5'W, 150°00.0'N, within 1 km of the bowheads.

T#/C#	LAT	LONG	TIME	BEH	HDG	ICE	SS	DEPTH	SEISMIC	DIST
1/0	70°53.9'	149°49.8'	1432	TR	330	2	1	18	YES	57
1/0	70°55.7'	149°50.0'	1432	TR	270	2	1	20	YES	57
4/0	70°55.8'	149°47.0'	1439	TR	270	2	1	22	YES	57
4/0	70°57.8'	150°03.9'	1605	TR	270	2	1	18	YES	57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LONELY
DEADHORSE
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BARTER IS.
HERSCHEL IS.
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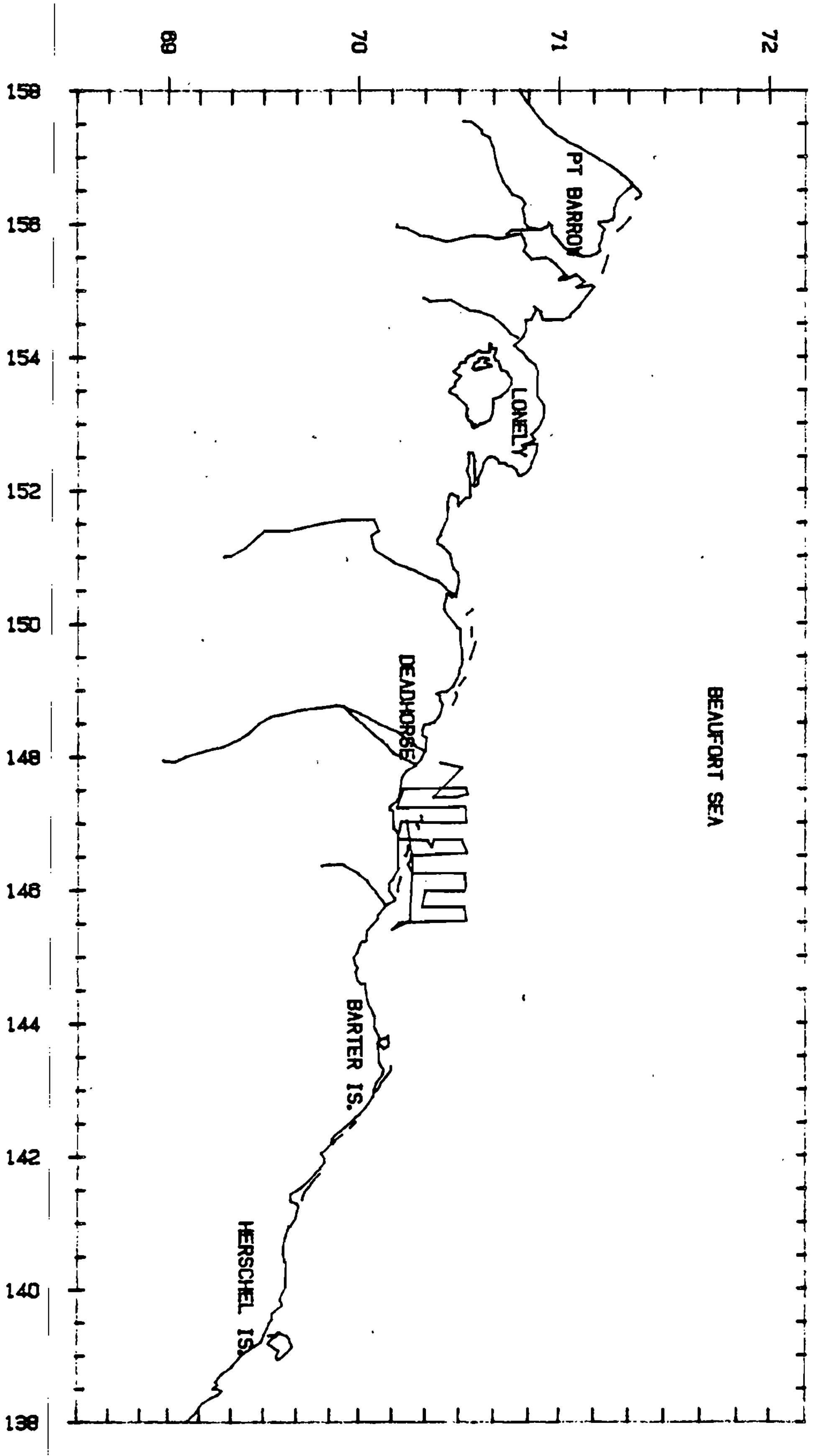
Flight 28: 18 September 1983

This flight was a grid survey of the GSI Alaskan at 70°22.2'N, 147°23.3'W, with two additional transects added onto the grid in order to monitor the area near the Western Aleutian at 70°21.6'N, 146°38.2'W. Ice coverage in the survey area varied from 0/10 to 9/10 broken floe, with a sea state of Beaufort 1. Weather was overcast with variable visibility. No bowheads were sighted. An unidentified pinniped was the only marine mammal seen. Seismic sounds from one geophysical vessel were recorded.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PT BARROW
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BEAUFORT SEA
BARTER IS.
HERSCHEL IS.

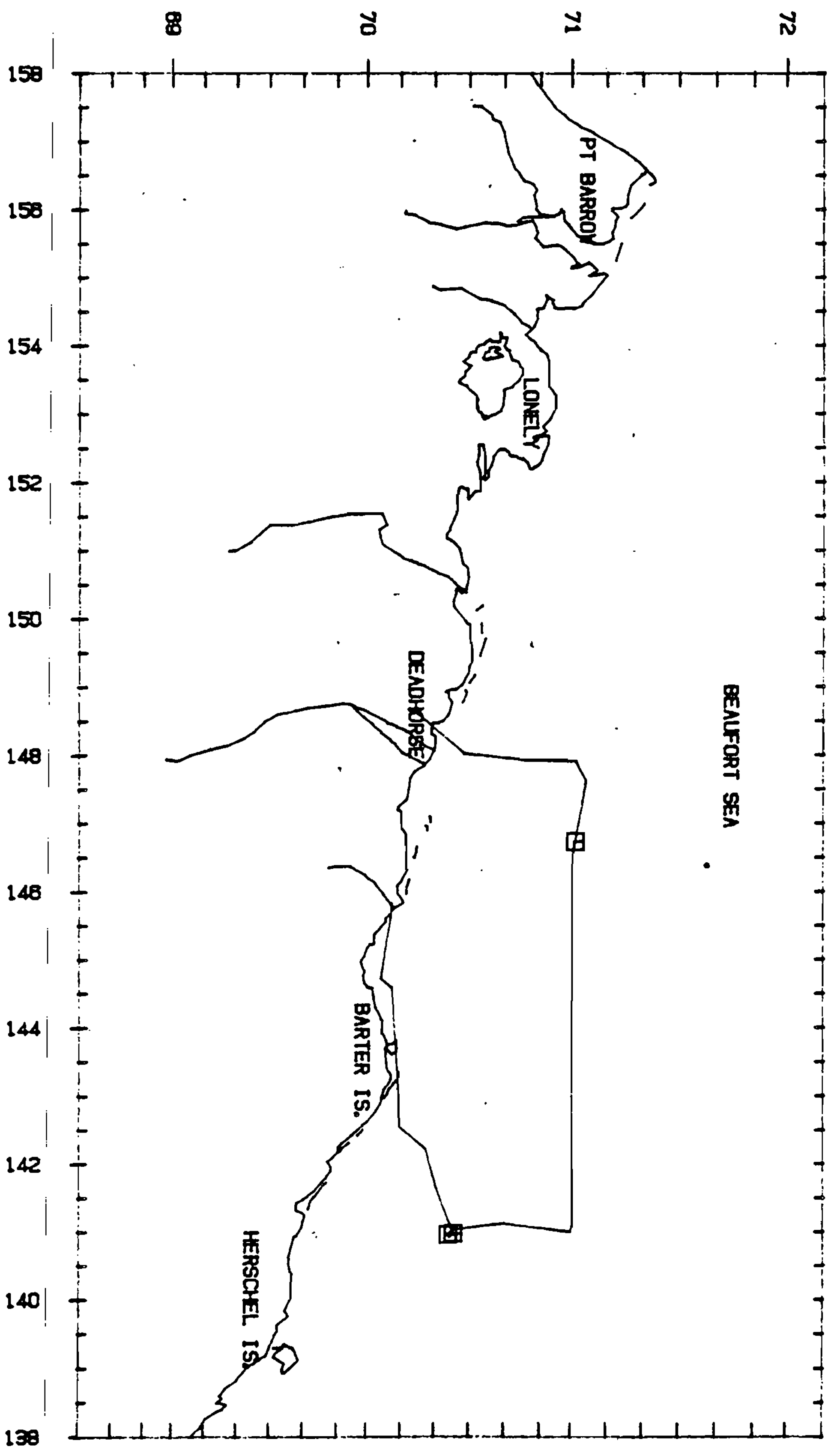
Flight 29: 18 September 1983

This flight was a search survey north from Deadhorse to 71°N and then east. Weather was overcast with unlimited visibility. Ice conditions in the area surveyed were 7/10 to 9/10 broken floe, and the sea state was Beaufort 0 to 1.

One sighting recorded as a probable bowhead was made at 71°01'N, 146°44'W. Later, four bowheads were seen in the vicinity of 70°25'N, 140°58'W. Initially one individual was seen breaching in a narrow lead. This solitary whale appeared to be milling and displaying at the surface when first sighted, but it seemed startled by the impact and activation of a sonobuoy that landed nearby. The whale had breached twice and blown once immediately before the sonobuoy landed, but it dove abruptly and then began swimming rapidly to the northwest within seconds after the sonobuoy struck the water. While searching for this whale after recording several more of its blow series, three more solitary bowheads appeared in or near the same lead. These appeared to be heading west or northwest at moderate speed.

A large herd of belukhas, estimated to include 150 animals of which 10-15 percent were calves, was within 3-5 km of the bowheads at 70°25.3'N, 141°01.5'W. The belukhas were in groups of 10-20 individuals and could be seen under the grease ice and in holes and leads near it. Unidentified pinnipeds were also seen on this flight. Sounds of bowheads and belukhas were recorded in this area, but no seismic sounds were heard. The nearest shooting seismic vessel was approximately 150 km to the west at 70°11'N, 145°04'W.

T#/C#	LAT	LONG	TIME	BEH	HDG	ICE	SS	DEPTH	SEISMIC	DIST
1/0	71°01.0'	146°44.0'	1409	NN	240	3	1	1098	NO	-
1/0	70°24.0'	140°57.5'	1521	BR	240	9	0	366	NO	150
3/0	70°25.6'	140°58.3'	1629	TR	270	9	0	366	NO	150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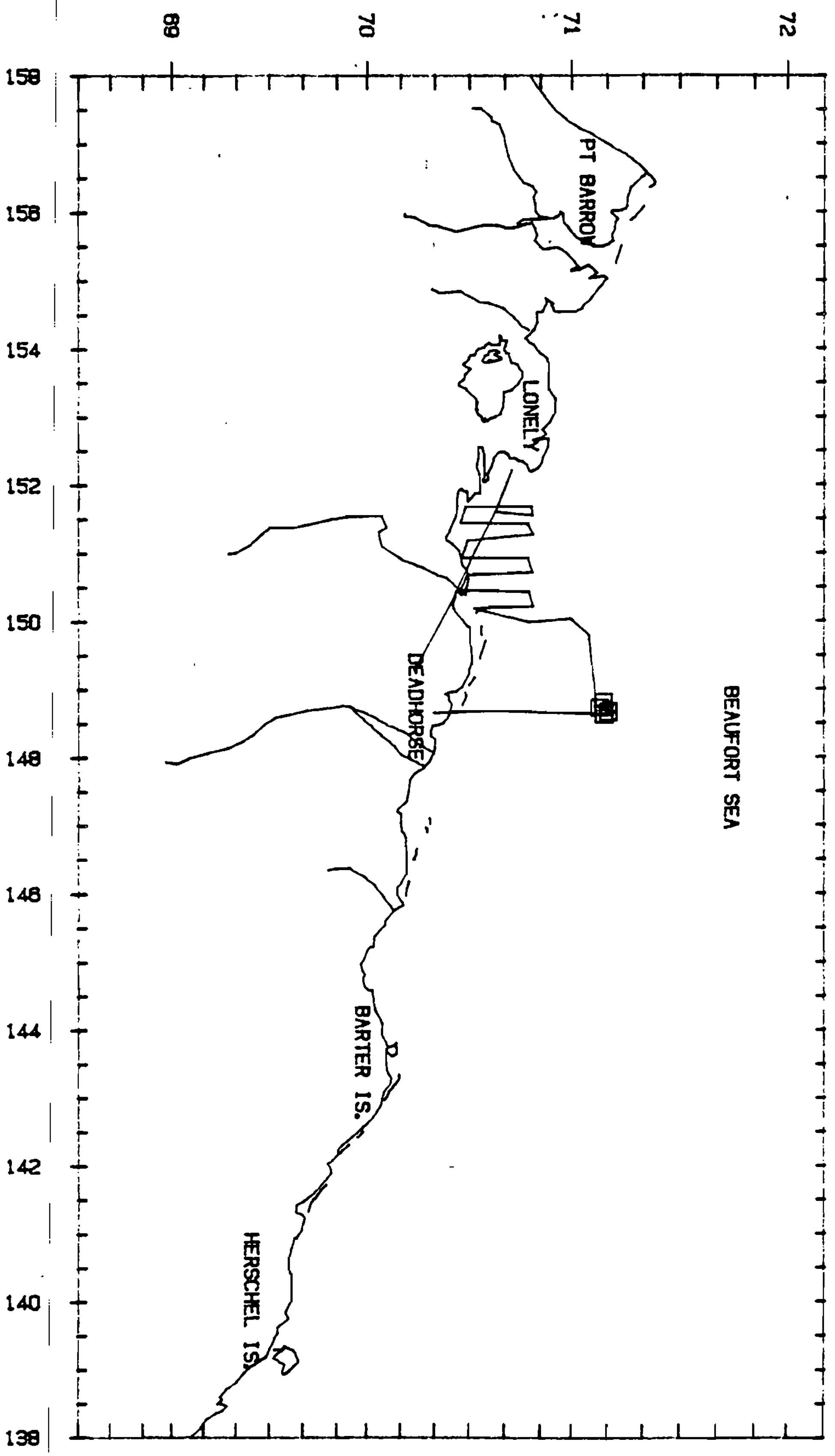
PT BARROW
LONELY
DEADHORSE
BARTER IS.
HERSCHEL IS.
BEAUFORT SEA

Flight 30: 21 September 1983

This flight was a grid survey of the Krystal Sea at 70°37.7'N, 151°35.9'W, and a search survey east along the 71°10'N latitude line. Ice coverage in the grid survey area was 0/10 with a sea state of Beaufort 1, and 4/10 to 5/10 broken floe with Beaufort 0 north of the 71°N latitude line. Weather was overcast with visibility ranging from 5 km to unlimited.

No bowheads were sighted during the grid survey, but eight, including two calves, were sighted in the area of 71°09'N, 148°43'W. Ice conditions in the 40 km^2 area of the whales varied from large open leads to 8/10 coverage. The whales were moving moderately fast to the south and west, and we had great difficulty relocating individuals after a dive. Belukha and seismic, but not bowhead, sounds were recorded.

T#/C#	LAT	LONG	TIME	BEH	HDG	ICE	SS	DEPTH	SEISMIC	DIST
1/0	71°08.0'	148°43.1'	1127	TR	240	5	0	137	YES	130
1/0	71°09.1'	148°47.9'	1138	TR	240	5	0	137	YES	130
3/0	71°10.5'	148°39.7'	1205	TR	150	4	1	183	YES	130
1/1	71°09.1'	148°37.3'	1222	TR	240	4	1	183	YES	130
2/1	71°09.3'	148°37.8'	1226	TR	190	4	1	183	YES	130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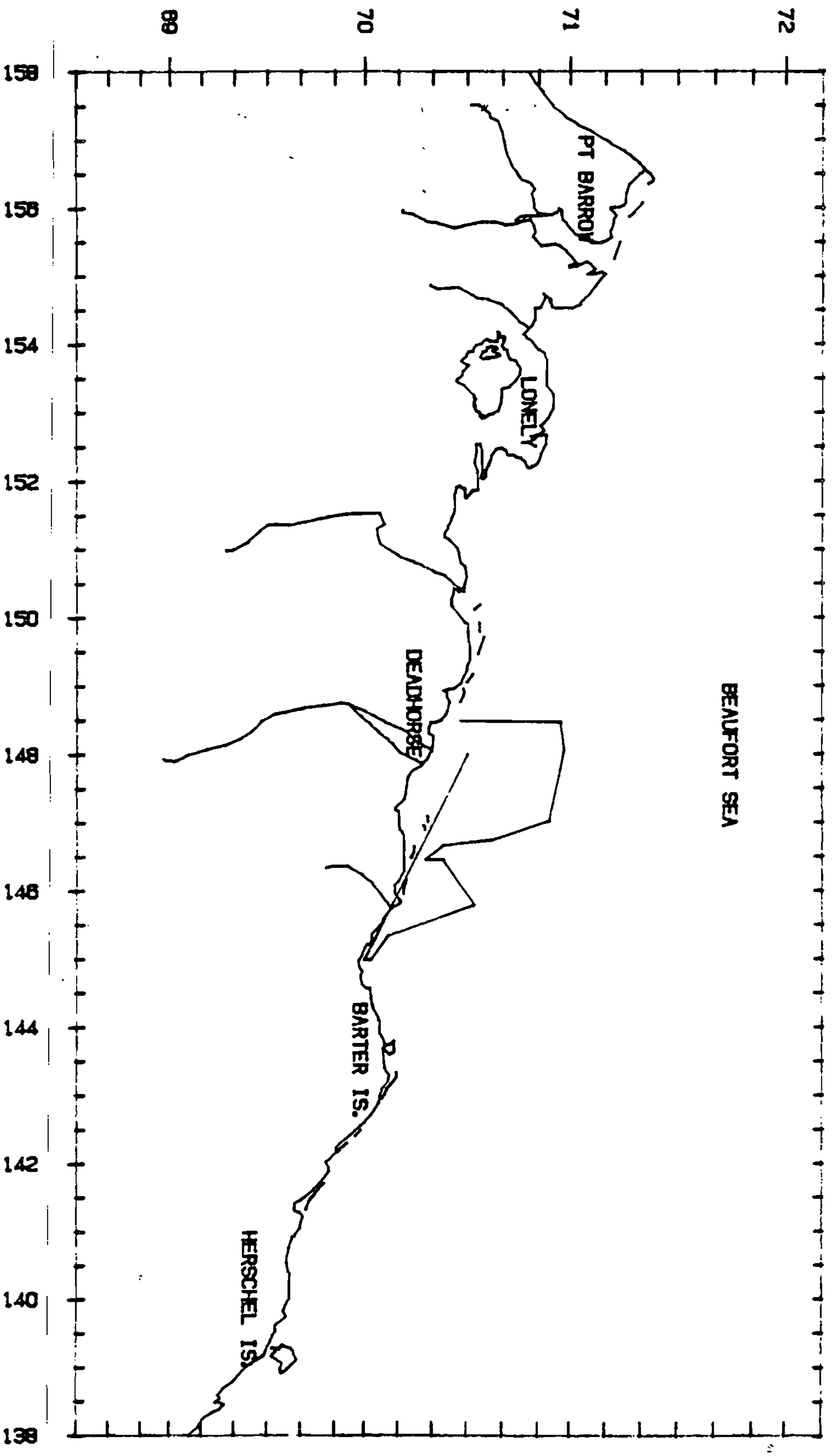
PT BARROW
LONELY
DEADHORSE
BEAUFORT SEA
BARTER IS.
HERSCHEL IS.

Flight 31: 22 September 1983

This flight was a search survey north from Deadhorse to 71°N and east. The aircraft's navigation system was not functioning properly, and the flight had to be aborted. Ice coverage was generally 2/10 broken floe south of 71°N and 7/10 to 9/10 north of this latitude. Sea state was Beaufort 1. Weather was patchy fog with poor visibility (less than 1 km to 5 km).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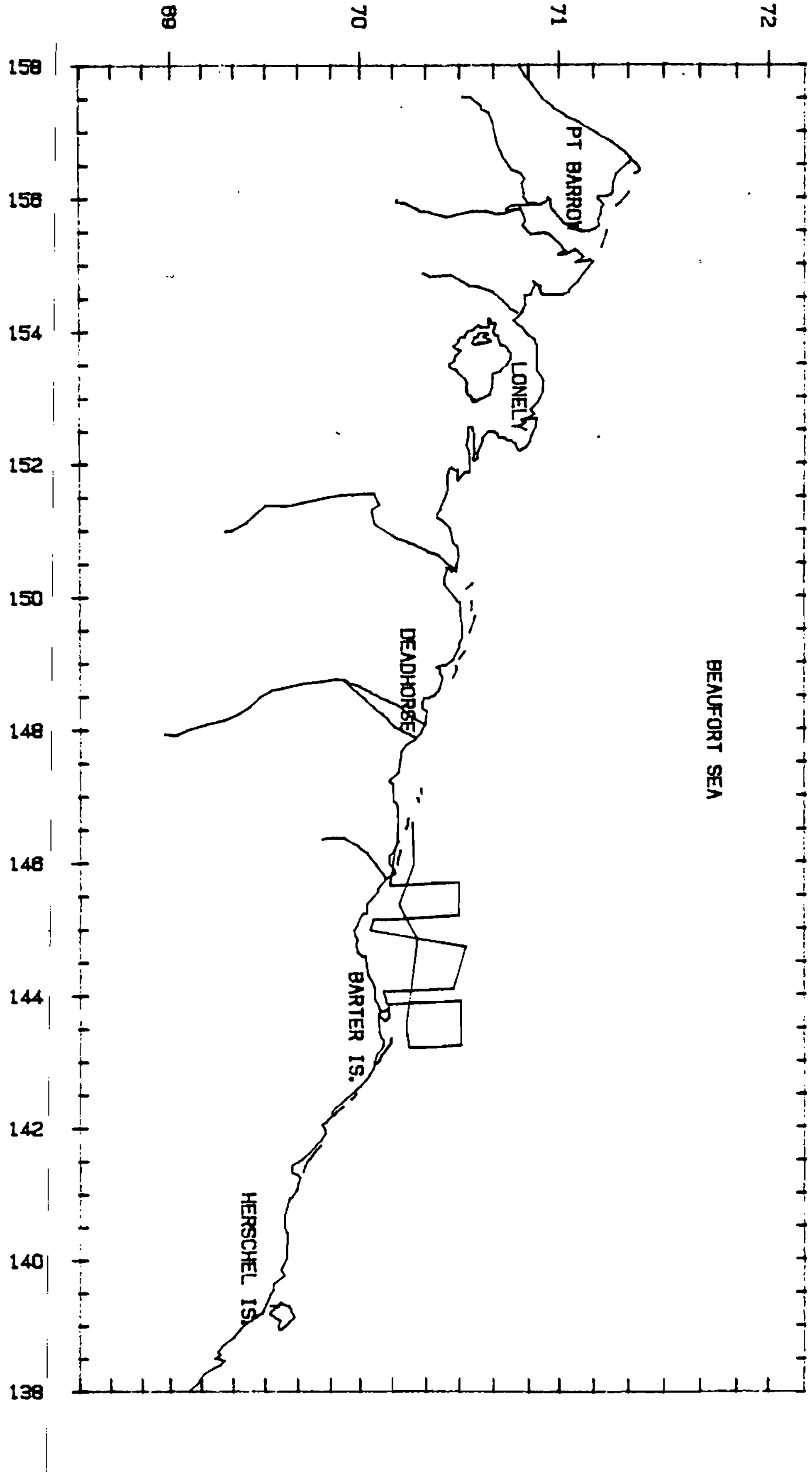
BEAUFORT SEA
BARTER IS.
HERSCHEL IS.

Flight 32: 23 September 1983

All geophysical vessels were either in dock or heading toward dock due to the rapid formation of grease ice on most of the open water in the Alaskan Beaufort Sea. This flight was a transect survey of Block 4 in support of the endangered whale study. Ice conditions in Block 4 were generally 5/10 to 9/10 broken floe or newly formed grease, and the sea state varied from Beaufort 1 to 5. Weather was patchy fog with variable visibility. No bowheads were sighted.



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PT BARROW
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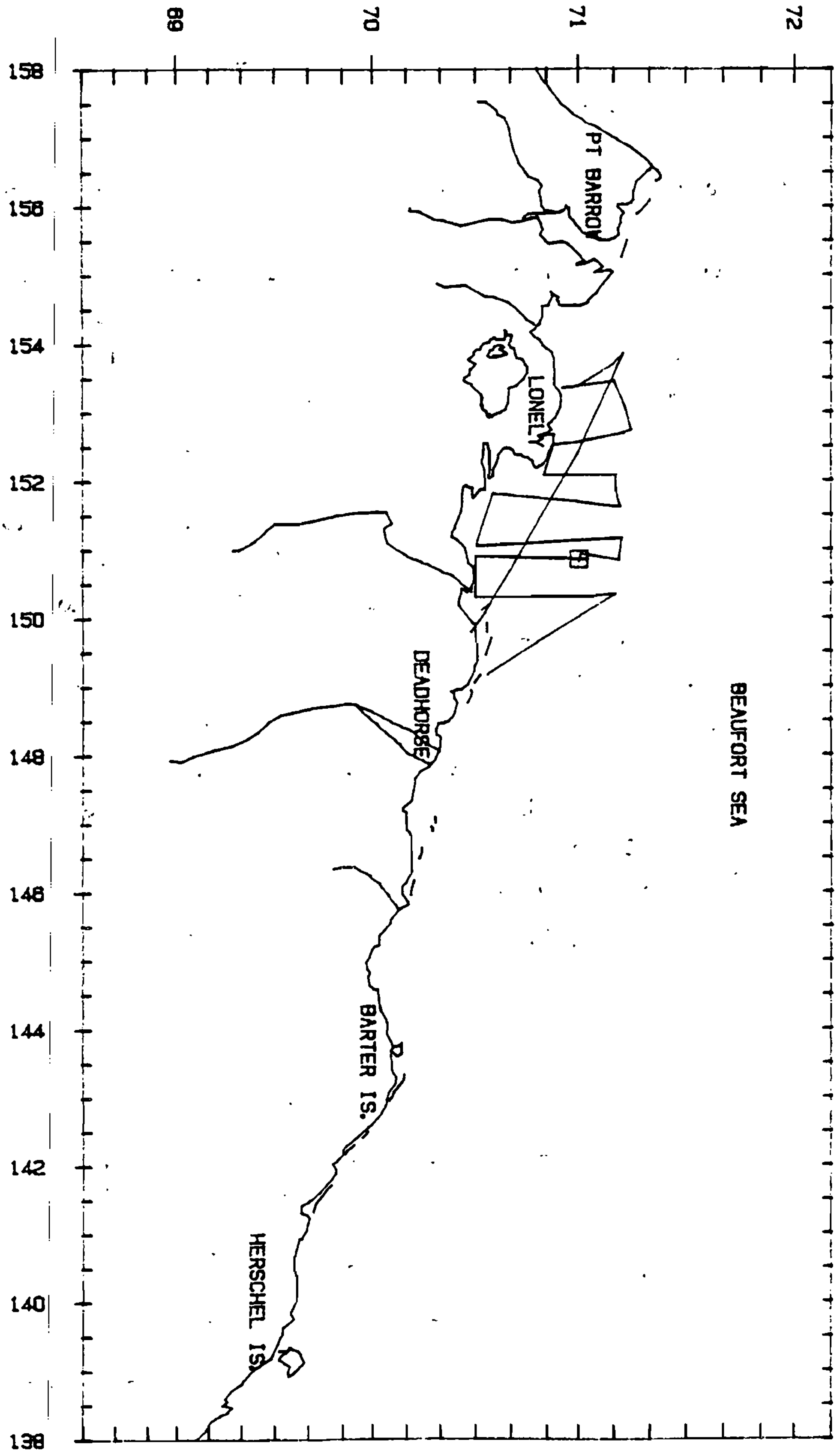
DEADHORSE
BARTER IS.
HERSCHEL IS.
BEAUFORT SEA

Flight 33: 25 September 1983

This flight was a transect survey of Block 3. Ice coverage was 5/10 to 9/10 broken floe in all areas except Harrison Bay, where there was still open water but where grease ice was forming on the fringes. Sea state was Beaufort 0 to 1. Weather was overcast and foggy, with visibility from 3 km to unlimited.

One bowhead was sighted at 71°00.5'N, 150°51.3'W. Twenty-five belukhas were seen at 1052 hr at 71°10.5'N, 150°21.5'W, heading west. Polar bears, walruses, and an unidentified pinniped were also seen.

T#/C#	LAT	LONG	TIME	BEH	HDG	ICE	SS	DEPTH	SEISMIC	DIST
1/0	71°00.5'	150°51.9'	1132	TR	240	9	0	20	NO	-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PT BARROW
LONELY
DEADHORSE
BEAUFORT SEA
BARTER IS.
HERSCHEL IS.

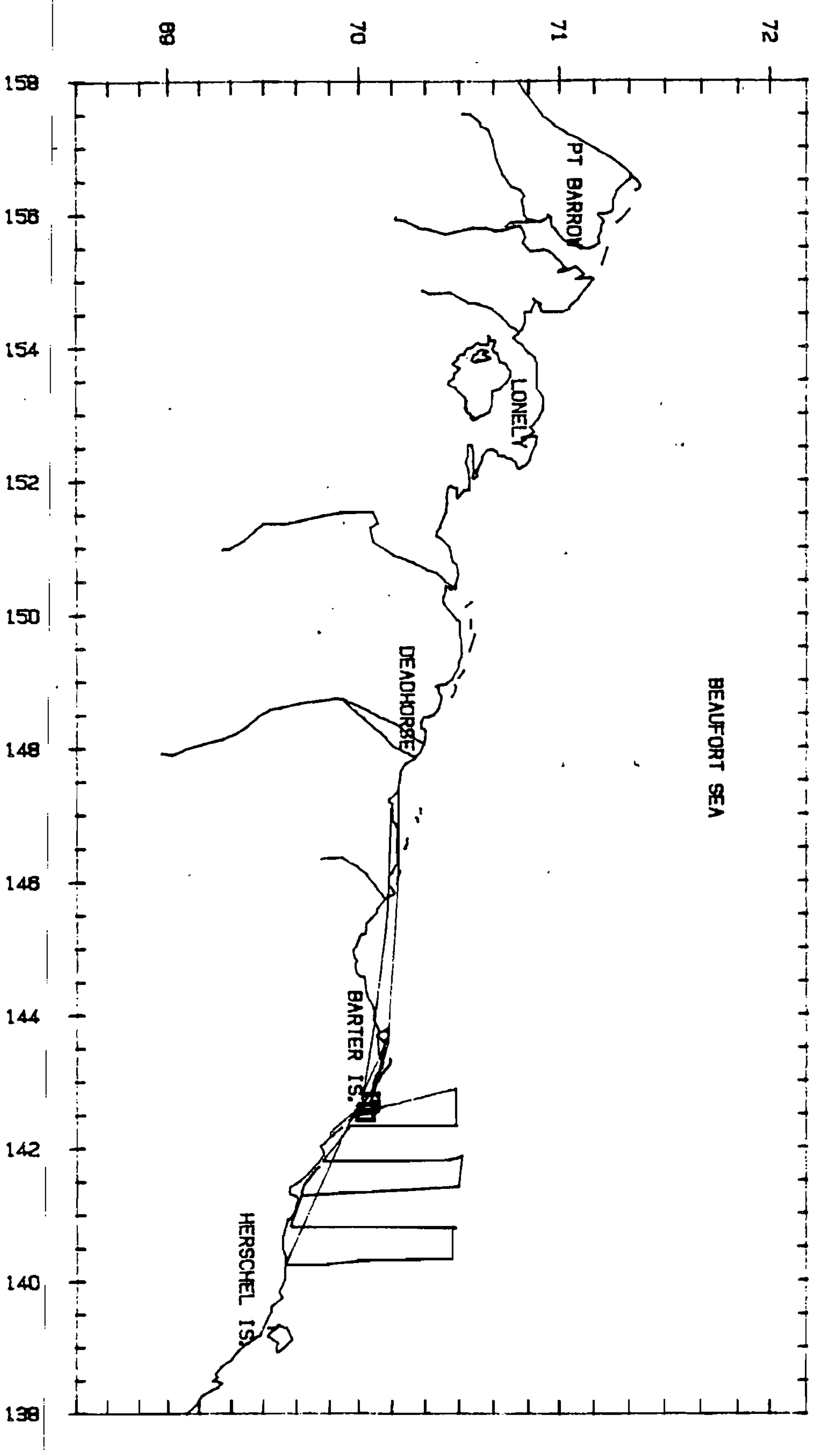
Flight 34: 26 September 1983

This flight was a transect survey of Block 5. Ice conditions in the block were 9/10 broken floe, and there was 5/10 to 6/10 grease ice close to shore. Sea state was Beaufort 0. Weather was overcast with unlimited visibility.

At 1033 hr a loosely associated group of approximately six bowheads was sighted at 70°02'N, 142°32'W, just east of Barter Island and in shallow (9 m) water within 1 km of shore. The ice here was 8/10 grease and slush. During the brief observation period, the whales were seen avoiding swimming through the grease and slush ice, preferring to pass under patches in order to surface only in areas of open water. They were milling and, judging by the inconsistent headings, probably feeding. After completing the Block 5 transects, a return flight to the same area revealed what was almost certainly the same group of whales at 1344 hr. One of them had a distinctive white mark on the peduncle which allowed for its recognition as an individual sighted earlier in the day. The whales were still milling, swimming slowly, and avoiding the grease ice. They showed no evidence of interaction. Some individuals fluked-up when diving; others did not. The whales' net westward movement between morning and afternoon (191 min elapsed time) was estimated to be 7.9 km, for a rate of 2.5 km/h. Some of this movement may have been caused by current. After one hour of observation, the plane departed to Deadhorse for fuel. During this flight, three groups of belukhas were seen. The first group of 25 was seen at 1139 hr at 70°30.8'N, 141°53.3'W, heading west. At 1230 hr, approximately 55 belukhas were seen at 70°28.9'N, 140°47.9'W, heading east. The third group, of three belukhas, was seen at 1236 hr at 70°28.3'N, 140°20.5'W. A polar bear and an unidentified pinniped were also seen.

T#/C#	LAT	LONG	TIME	BEH	HDG	ICE	SS	DEPTH	SEISMIC	DIST
2/0*	70°02.3'	142°32.1'	1033	FE	240	9	0	9	NO	-
1/0*	70°01.9'	142°33.3'	1036	FE	240	9	0	9	NO	-
1/0*	70°01.6'	142°32.7'	1037	FE	300	9	0	9	NO	-
2/0*	70°02.0'	142°34.4'	1038	FE	330	9	0	9	NO	-
1/0*	70°03.8'	142°43.0'	1335	FE	330	9	0	9	NO	-
1/0*	70°03.8'	142°43.0'	1335	FE	180	9	0	9	NO	-
1/0*	70°03.8'	142°43.0'	1335	FE	300	9	0	9	NO	-
3/0*	70°03.8'	142°42.6'	1339	FE	-	9	0	9	NO	-
1/0*	70°03.5'	142°40.8'	1340	FE	060	9	0	9	NO	-

*All sightings listed refer to members of a loosely associated group of approximately 6 different individuals seen repeatedly.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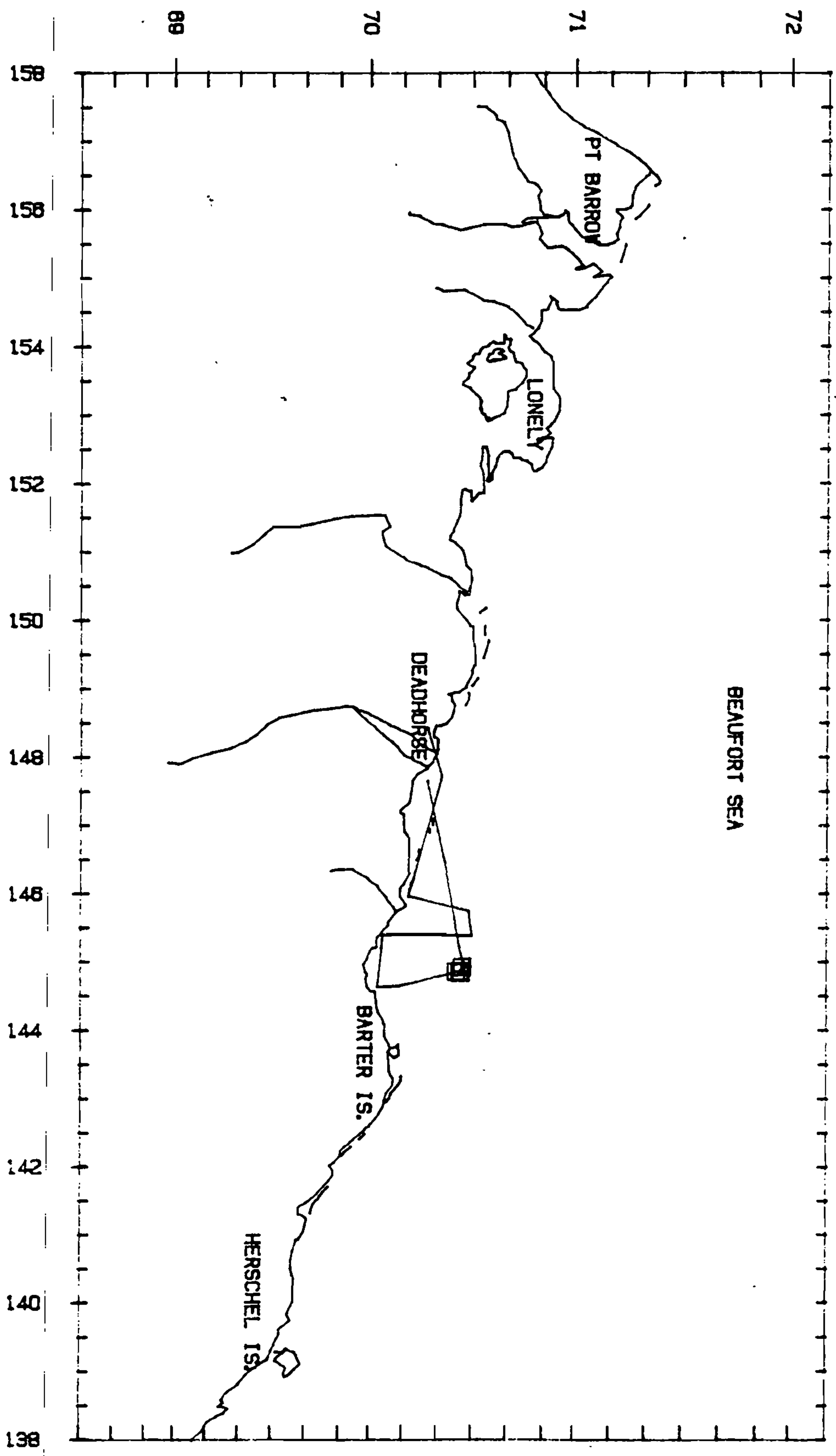
PT BARROW
LONELY
DEADHORSE
BARTER IS.
HERSCHEL IS.
BEAUFORT SEA

Flight 35: 27 September 1983

This flight was a transect survey of the western half of Block 4. Ice coverage was 7/10 to 9/10 broken floe and grease, with a sea state of Beaufort 0. Weather was overcast with unlimited visibility.

Approximately 7 to 10 bowheads were sighted at or near 70°26'N, 144°52'W. The immediate area had 4/10 broken floe ice and numerous leads, surrounded by 9/10 broken floe ice. The whales were swimming west and northwest at speeds ranging from slow to fast. They tended to have long blow series and did not dive deep between surfacing periods. Many could often be seen swimming just below the surface between blows. In one instance, two whales swimming moderately fast to the west and within a whale length of each other slowed to a stop as they approached the edge of an ice cake, then dove under it. On two other occasions small individuals, upon approaching the edge of a large pan, turned and swam parallel to it for three to five whale lengths before diving under the ice. An unidentified pinniped was also seen on this flight. Bowhead sounds were recorded.

T#/C#	LAT	LONG	TIME	BEH	HDG	ICE	SS	DEPTH	SEISMIC	DIST
2/0	70°25.6'	144°52.5'	1018	TR	240	7	0	42	NO	-
2/0	70°26.7'	144°52.4'	1022	TR	280	7	0	42	NO	-
1/0	70°26.9'	144°52.0'	1026	TR	-	7	0	42	NO	-
1/0	70°26.7'	144°51.8'	1038	TR	-	7	0	42	NO	-
1/0	70°27.2'	144°56.5'	1049	TR	-	7	0	42	NO	-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PT BARROW
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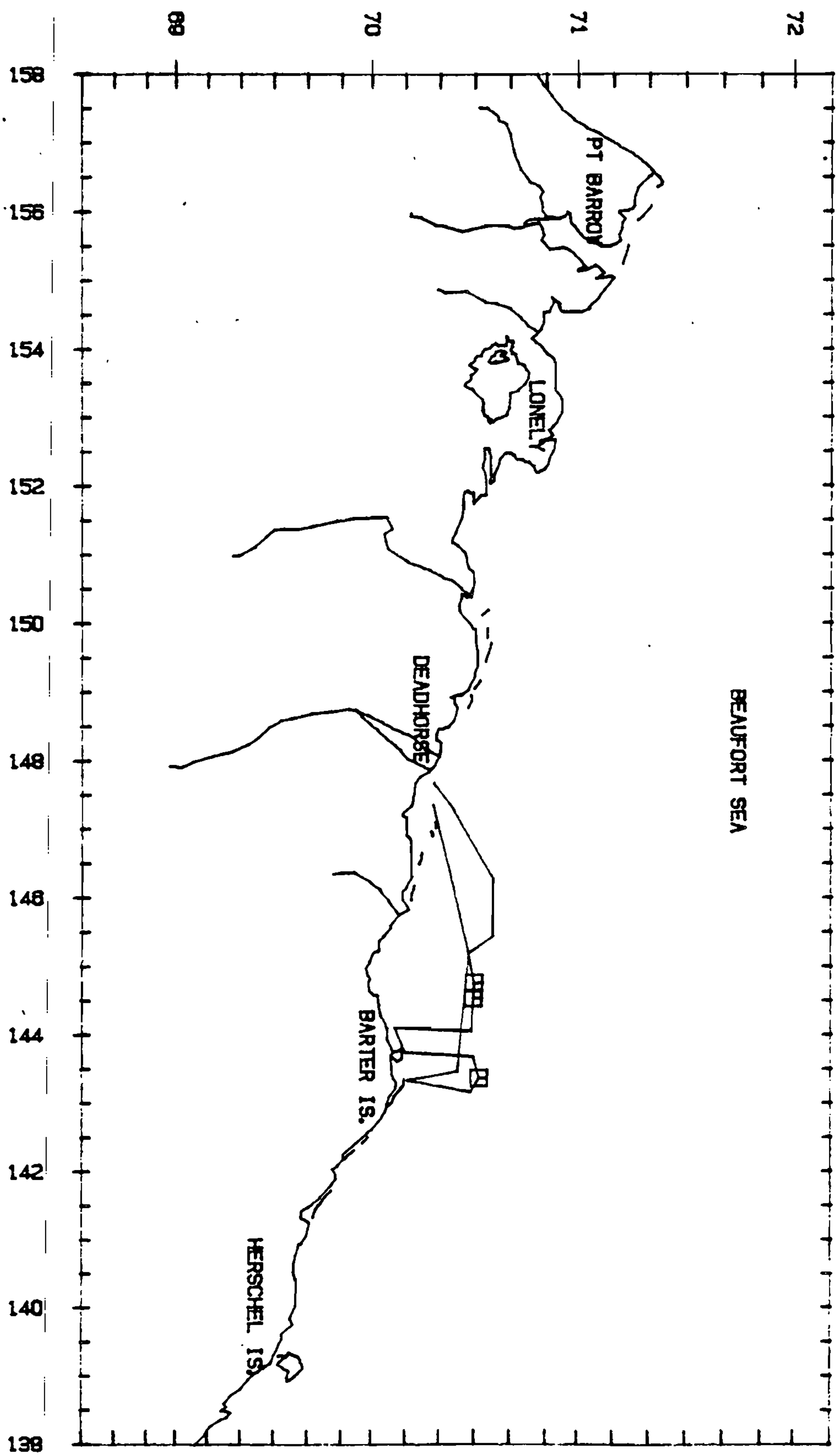
BARTER IS.
HERSCHEL IS.

Flight 36: 27 September

This flight was a transect survey of the eastern half of Block 4. Three bowheads and one "footprint" (a large slick left on the surface after a whale has dived) were sighted. The whales' headings were west and southwest. Ice coverage was 7/10 to 9/10 broken floe and grease, with a sea state of Beaufort 0. Weather was overcast with unlimited visibility.

T#/C#	LAT	LONG	TIME	BEH	HDG	ICE	SS	DEPTH	SEISMIC	DIST
2/0	70°29.8'	144°45.9'	1437	TR	230	8	0	42	NO	-
1/0	70°29.6'	144°32.6'	1442	TR	180	8	0	46	NO	-
1/0	70°31.2'	143°22.4'	1515	NN	240	9	0	46	NO	-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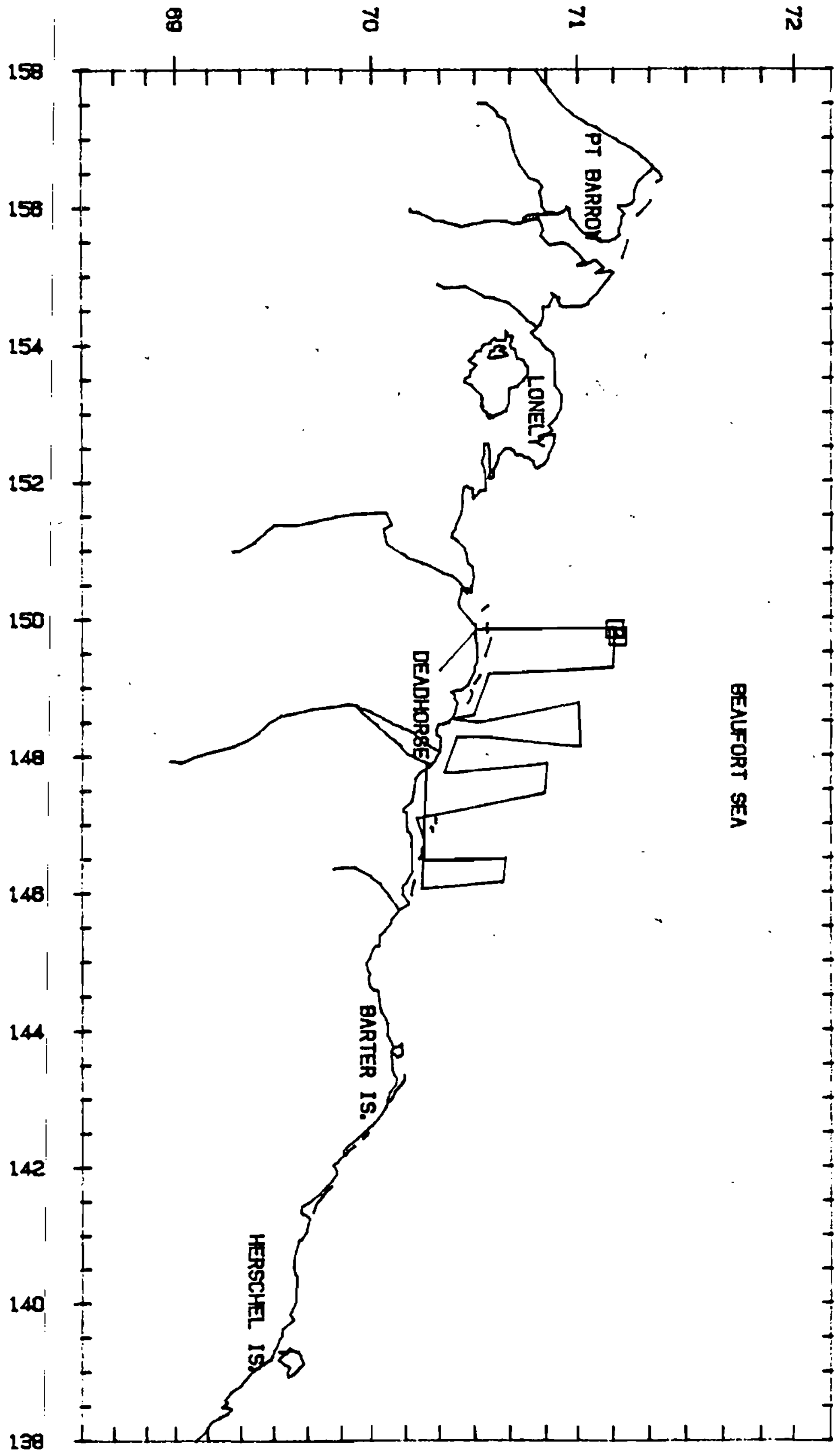
Flight 37: 28 September 1983

This flight was a transect survey of Block 1. Ice coverage was 7/10 to 9/10 broken floe and grease, with a sea state of Beaufort 1. Weather was clear with unlimited visibility. Three bowheads, including a cow-calf pair, were sighted at 71°10.3'N, 149°50.9'W. All three were heading west at a moderate speed. The calf was swimming above the cow for a time.

T#/C#	LAT	LONG	TIME	BEH	HDG	ICE	SS	DEPTH	SEISMIC	DIST
1/0	71°11.1'	149°44.2'	1035	TR	240	2	1	183	NO	-
2/1	71°10.3'	149°50.9'	1037	TR	240	2	1	183	NO	-


PT BARROW
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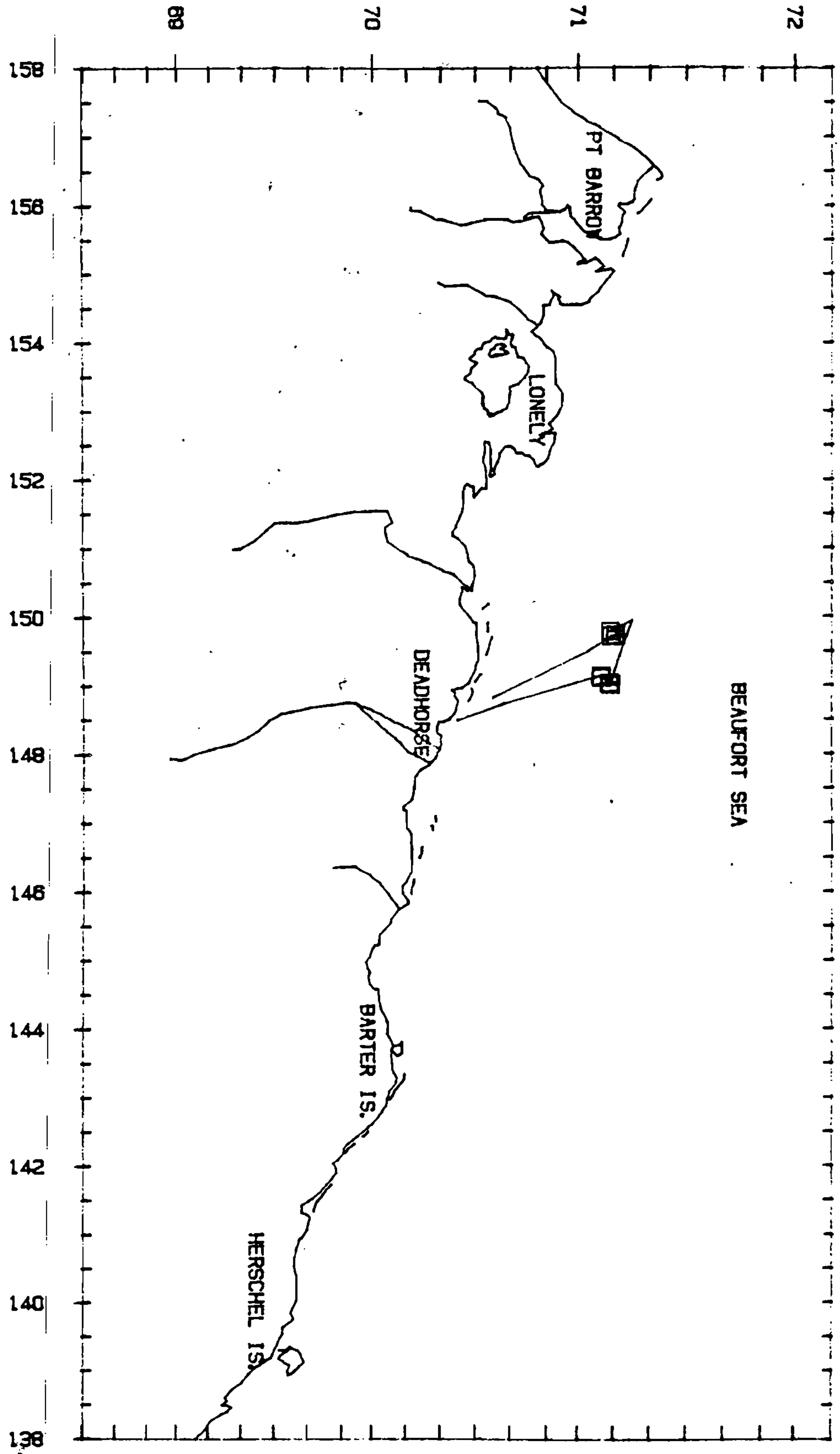
Flight 38: 28 September 1983

This flight was a search survey of the area where bowheads were seen on flight 37. Ice coverage was 7/10 to 9/10 broken floe and grease, with a sea state of Beaufort 1. Weather was clear with unlimited visibility. Nine bowheads, including two cow-calf pairs, were sighted in the area of 71°10'N, 149°45'W. All were heading west and were separated by distances of at least 100-150 m (the cow/calf pairs being taken as separate units). One large solitary whale appeared to respond to the aircraft (circling at 490 m a.s.l.) by rolling onto its side, making a 90° change in course, and sinking tail-first until lost from view. Considerable quantitative data on the cow-calf pairs were collected. The second pair remained for more than 30 min in a pond of open water about 1 km in diameter, moving slowly. After they dove under a solid sheet of ice 5.9 km across, they were not re-sighted, in spite of a prolonged and intensive search of the area. Seven belukhas were seen at 1530 hr at 71°14.8'N, 149°58.0'W. All were heading 120°(M). No other marine mammals were seen.

T#/C#	LAT	LONG	TIME	BEH	HDG	ICE	SS	DEPTH	SEISMIC	DIST
1/0	71°09.1'	149°44.2'	1436	TR	300	7	1	183	NO	-
3/1	71°10.2'	149°44.9'	1440	SI	270	7	1	183	NO	-
1/0	71°08.7'	149°48.1'	1500	TR	260	4	1	183	NO	-
1/1	71°08.9'	149°01.4'	1547	SI	210	5	1	62	NO	-
1/0	71°08.4'	149°02.8'	1554	SI	210	5	1	62	NO	-
1/0	71°06.3'	149°07.4'	1647	TR	280	5	1	62	NO	-
1/0	71°06.0'	149°09.2'	1744	TR	220	5	1	62	NO	-



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PT BARROW
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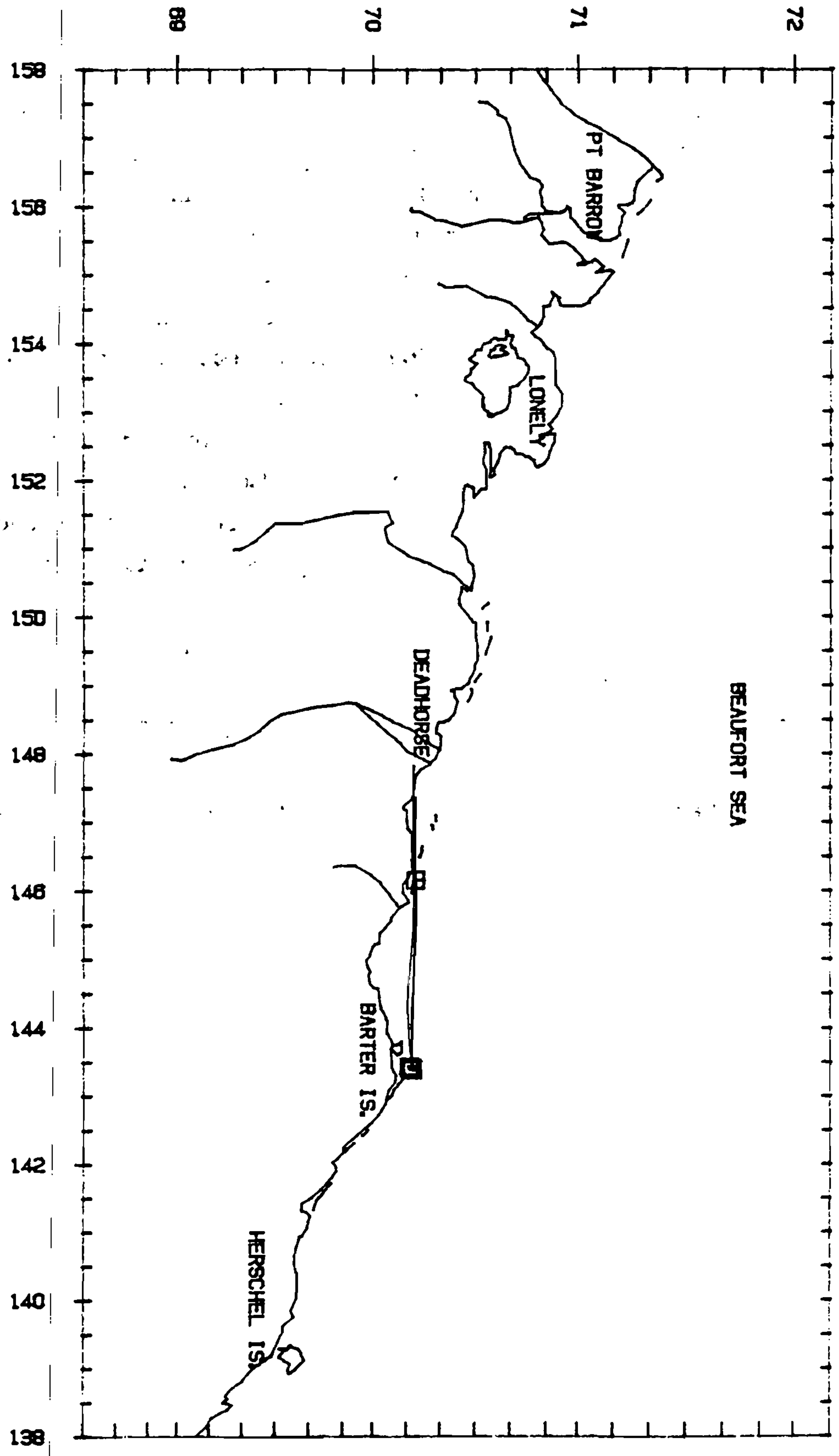
BEAUFORT SEA
BARTER IS.
HERSCHEL IS.

Flight 39: 29 September 1983

This flight was a search survey east from Deadhorse to Barter Island. Ice conditions near Barter Island were 5/10 grease and slush, with a sea state of Beaufort 0 to 1. North of Flaxman Island, ice conditions were 8/10 grease and slush, with a Beaufort 3 sea state. Weather was initially clear with unlimited visibility. Approximately eight to ten bowheads, thought to be feeding, were sighted at 70°11.6'N, 143°25.5'W, within one km of shore and just east of Barter Island. Their headings were not consistent, and they were making what appeared to be both shallow and steep dives in water about 11 m deep. After close to two hrs of observation, the plane was forced by fog to leave the area. While en route to Deadhorse to refuel, four bowheads were sighted at 70°12.7'N, 146°10'W, one km north of Flaxman Island. These were observed for only a short time before fuel requirements forced a return to Deadhorse.

T#/C#	LAT	LONG	TIME	BEH	HDG	ICE	SS	DEPTH	SEISMIC	DIST
3/0	70°11.6'	143°25.5'	0951	FE	090	5	0	11	NO	-
1/0	70°11.2'	143°24.9'	0958	FE	240	5	0	11	NO	-
1/0	70°10.9'	143°27.0'	1001	FE	-	3	1	11	NO	-
3/0	70°11.9'	143°24.0'	1205	FE	-	3	1	11	NO	-
4/0	70°12.7'	146°10.2'	1222	MI	210	8	1	7	NO	-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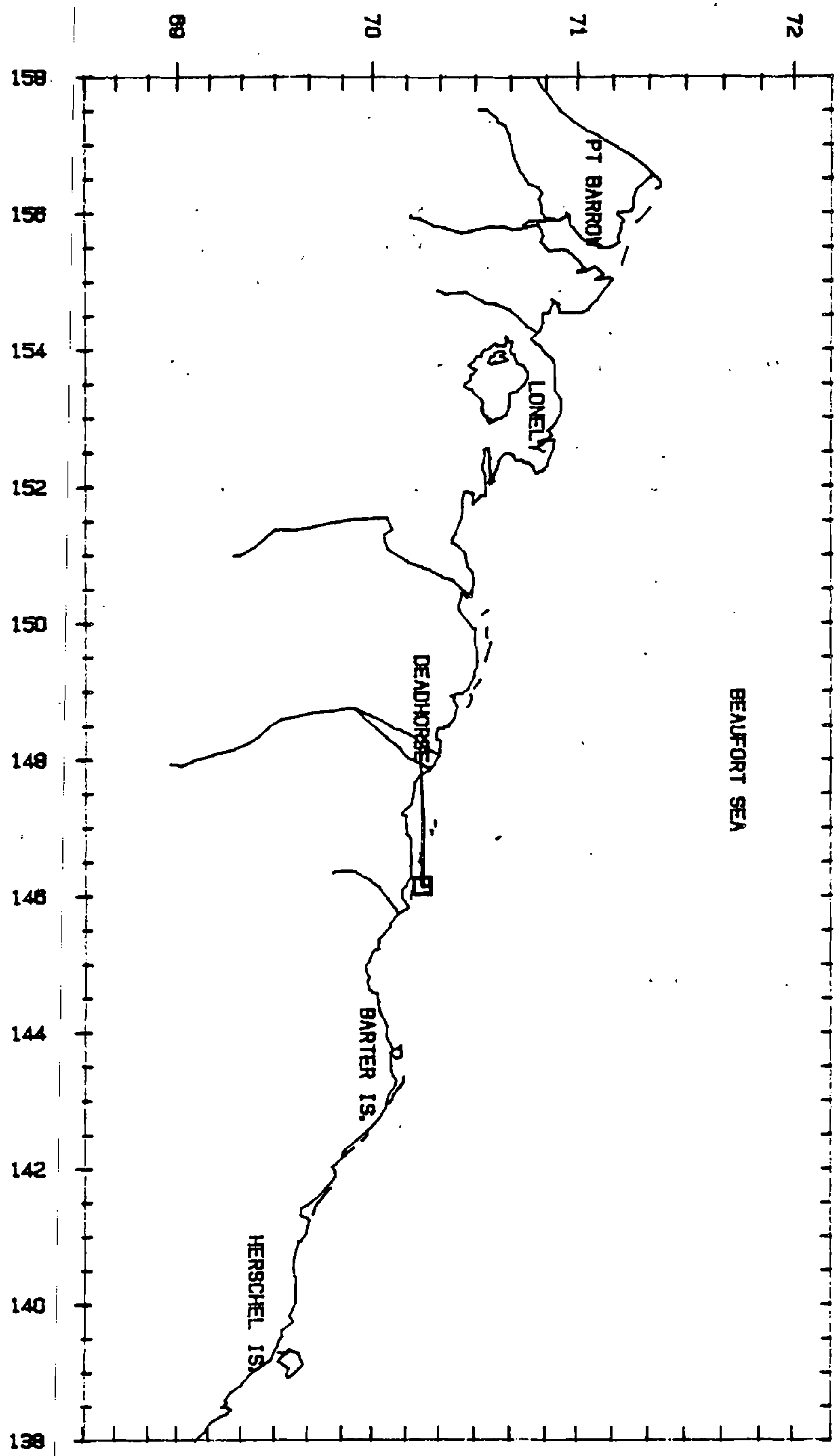
Flight 40: 29 September 1983

This flight was a search survey east from Deadhorse to Flaxman Island to attempt to relocate the bowheads seen earlier on Flight 39. Ice conditions were 8/10 grease and slush, with a sea state of Beaufort 2 to 3. Weather in the vicinity of Flaxman Island was clear with unlimited visibility. Approximately 10 bowheads were found at 70°14'N, 146°10'W, one km north of the island. Their behavior was essentially the same as that of the bowheads observed earlier in the day near Barter Island. The tendency of the whales to avoid the slush and grease ice when surfacing was reminiscent of the observations made on September 26 (Flight 34). Even when they encountered small patches of ice, the whales chose to dive underneath them and surface on the opposite side rather than to swim through such patches. Shortness of surface times was noted (sometimes consisting of a single blow) and, with the rapid development of slush and grease ice and the deteriorating light conditions, it became increasingly difficult to detect whales and observe them through a complete surface and dive sequence. At 1640 observations were terminated and the plane returned to Deadhorse.

T#/C#	LAT	LONG	TIME	BEH	HDG	ICE	SS	DEPTH	SEISMIC	DIST
1/0	70°14.3'	146°09.1'	1435	MI	240	8	2	7	NO	-
9/0	70°13.8'	146°10.2'	1544	MI	-	8	2	7	NO	-



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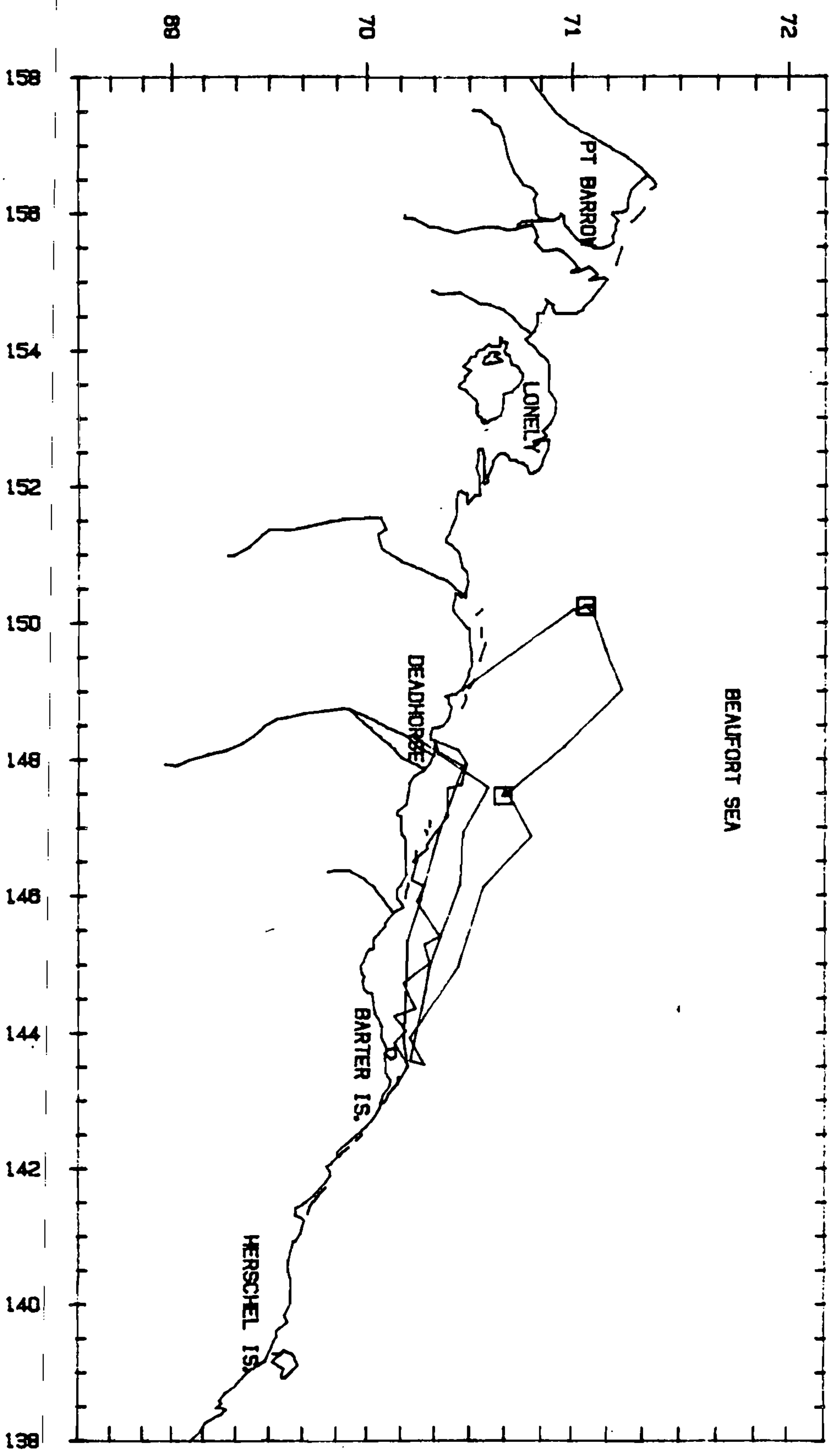
BARTER IS.
HERSCHEL IS.
BEAUFORT SEA

Flight 41: 30 September 1983

This flight was a search survey east from Deadhorse along the 20 m isobath to Barter Island, then northwest to the area where whales had been seen on Flight 38. Ice conditions were 4/10 to 5/10 grease and slush south of 70°20'N, and 9/10 broken floe and grease north of there. Sea state was Beaufort 1 to 2. Weather was overcast with unlimited visibility. One bowhead was sighted during one surfacing series at 70°40.2'N, 147°36.4'W, directly in the path of the Canadian icebreaker Terry Fox. The vessel was heading east at a speed we estimated as greater than 10 kt. It appeared to be moving through the 9/10 grease ice in the area with little difficulty. The whale was less than 1 km in front of the vessel and heading east, swimming rapidly and remaining near the surface. Observations of the whale were brief, and no quantitative data on its behavior were collected. It was assumed that the whale either sounded deep or changed its course before being overtaken by the vessel. The whale may have been fleeing.

Two more bowheads were sighted briefly at 71°03.8'N, 150°15.5'W in 9/10 grease ice. They were solitary and headed due west at moderate speed. Neither whale could be resighted in spite of persistent circling and searching. A bearded seal was also seen. A sonobuoy was dropped near the Terry Fox, and loud vessel noise recorded.

T#/C#	LAT	LONG	TIME	BEH	HDG	ICE	SS	DEPTH	SEISMIC	DIST
1/0	70°39.5'	147°29.1'	1558	TR	090	9	1	38	NO	-
1/0	71°03.8'	150°15.5'	1648	TR	290	9	1	18	NO	-
1/0	71°04.1'	150°14.6'	1652	TR	240	9	1	18	NO	-



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APPENDIX B

SEISMIC SURVEY SIGNALS IN THE SHALLOW BEAUFORT SEA

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INTRODUCTION

The continental shelf north of Alaska has become an important area for geophysical surveys searching for hydrocarbon deposits. The Minerals Management Service (MMS) of the U.S. Department of Interior is responsible for exploration leases in offshore areas and has supported research to learn about the effects of oil and gas industry activities on the environment. In particular, MMS has supported the Naval Ocean Systems Center (NOSC) since 1979 to conduct aerial surveys of bowhead whales during their westward migration along the north Alaska coast. There is concern that underwater sounds from industrial activities may disturb these animals and perhaps even cause them to alter their migration patterns. Thus, NOSC has used sonobuoys to monitor underwater sounds in the vicinity of whales. Of the different types of sounds heard, the strongest are seismic survey signals, which may be received at ranges exceeding 80 km, even in shallow water. In 1983 NOSC arranged for Greeneridge Sciences, Inc., to send an underwater-sound specialist to sea on a supply vessel to record seismic survey signals at close range, using the airgun array on a cooperating survey vessel as the signal source.

Experimental Conditions

Ice conditions north of Alaska in September 1983 were such that ships had a difficult time operating and many plans, made by geophysical survey companies and research parties alike, were thwarted. The heavy ice remained very close to the coast. On 21 September, the acoustician took his equipment aboard Northern Lighter, a 38 m supply vessel operated by Western Geophysical, Inc. On 22 September, after resupplying two survey ships in Camden Bay (near Barter Island), Northern Lighter met the survey vessel Western Polaris northwest of Camden Bay just before 18:30 Alaska Daylight Time (ADT). Two hydrophones at depths of 9 and 18 m were over the side of Northern Lighter, which was adrift. Western Polaris steamed away at the normal speed for conducting surveys, 4 to 4.5 knots, firing the airgun array in the usual manner (12 s between firings).

There were ice floes in the vicinity, with the total ice coverage about 3/10. The sky was clear, the wind was calm and the sea surface was nearly flat. The water depth was 20 m. It was essential for Northern Lighter to keep all its generators running and the main propulsion engines idling during the recordings; therefore the background noise level was quite high.

Terminology

Several terms familiar to acousticians have been used in this report. To aid other readers we have provided brief definitions below.

Absorption loss: a loss of sound energy to molecular action. It can be described as a loss of so many dB per unit distance traveled. Losses from absorption into the bottom and scattering at the surface can also be described this way in shallow water when sound rays are reflected many times between the surface and bottom.

Spherical spreading: sound pressure diminishes with range simply because it spreads out from a local source. In a linear medium without refraction or reflecting surfaces the wavefronts are spherical and the spreading loss can be described in dB by computing 20 log(R/RO), where RO is unit range or some reference range.

Cylindrical spreading: sound spreads out from a source but is reflected at the surface and bottom repeatedly. The wavefronts become cylindrical and the spreading can be described in dB as 10 log(R/RO), where RO is unit range or some reference range.

Finite amplitude effects: effects from signals so strong the water is displaced a finite amount by the pressure wave. In normal acoustic signal propagation the displacement is infinitesimal and no energy is lost to heating the medium. Signals from airguns are large and do not become 'acoustic' in the above sense until they have spread out from the source a substantial distance.

METHODS

Airgun Array

The airgun array on Western Polaris was deployed on four lines behind the ship. The lines streamed parallel to one another and were 2.4 m apart. Each line contained six airguns spaced 2.4 m apart. The forward airguns in the two outside lines were 4.3 m from the ship's stern; the forward airguns in the inner two lines were 43.9 m behind the stern. In use, 18 or 20 guns were used simultaneously for a total source volume of 27.9 L (1700 cu in). The source level was reported to be 30 bar-m. Airgun source levels are usually stated as peak-to-peak levels, in which case the source level of this array would be equivalent to 244 dB//1uPa-m peak. The towing speed was on the order of 4 to 4.5 knots and the interval between firings was 12 sec.

Recording Procedure

A crew member on the bridge of Northern Lighter recorded radar ranges to Polaris during the experiment, logging the time whenever the range increased by an additional 0.23 km (1/8 n mi). Recording continued from a range of 1.62 km (7/8 n mi) until Polaris was beyond 7.41 km (4 n mi). Then recordings were made for short periods when Polaris reached 9.27 km (5 n mi) and 11.12 km (6 n mi).

Equipment

The hydrophones at 9 and 18 m were wideband, low-noise model H56 hydrophones from the Naval Research Laboratory, Orlando, Florida. These two units had sensitivities of -172 dB//1volt/microPascal and were capable of receiving pressure signals with levels of 189 dB//1uPa without distortion. Signals were recorded on a Fostex Model 250 four-channel cassette tape recorder. This recorder has a servo-controlled capstan for speed stability to assure the preservation of the signal frequencies being recorded. The two hydrophone signals and a voice channel were recorded simultaneously.

Analysis Procedure

Analysis involved playing back the tape and digitizing selected segments for analysis with a general purpose computer. The analog-to-digital converter provided 12-bit samples at a rate determined by the operator. For waveform (time series) analysis of the seismic signals the sample rate was 2048 samples per second. For spectrum analysis of the background signals before and after the experiment the sample rates were 2048 and 16,384 sample/s.

Analysis of the seismic signal waveforms followed the format used in analyzing seismic signals received in the Canadian Beaufort Sea and reported in Greene (1982, pp 313-320, and 1983, pp 236-245 and 262-264). The digitized waveforms were plotted, and the maximum amplitude was measured on the plot. By squaring the maximum amplitude, dividing by 2, and computing 10 times the logarithm (base 10) of that result, we derived the effective level of the signal in dB with respect to 1 volt. The term 'effective' is used because although the first measurement is of a maximum or peak level, the final computation is of the level we would have measured had the signal been a sinusoid with the same maximum level. The term 'effective' is synonymous with 'root-mean-square', or 'rms'. In the remainder of this report we will shorten 'effective received pressure level' to 'received level'.

Measuring the average period of the signal in the vicinity of the maximum amplitude permitted computing the frequency by taking the inverse of the period.

(The signals were generally periodic in nature.) Then, combining the hydrophone sensitivity with the tape recorder amplification (or attenuation) at the signal frequency, we obtained the system sensitivity in dB with respect to 1 volt per microPascal. Finally, we subtracted the system sensitivity from the effective level of the signal to obtain the effective received pressure level of the signal in dB with respect to 1 microPascal (dB//1uPa).

From discrete Fourier transforms we derived estimates of power spectral densities; these characterized the background noise. The process will be described in detail for signals sampled at the rate of 2048 samples per second. A total of 17,408 samples were stored, or 8.5 s. These were divided into one set of eight segments, each 2048 samples long, and a second set of eight additional segments of the same length but overlapping the first segments by 50%. Thus, the first 1024 samples were used only once (in the first segment in the first set) and the last 1024 samples of the original 17,408 were used only once (in the last segment in the second set). All other samples were used in two segments. The 2048 samples in each segment were weighted by the 'minimum 3-term Blackman-Harris' window (Harris, 1978) to minimize undesirable effects of the discrete Fourier transform. The weighted samples were transformed, the power spectrum computed, and then the power spectra for all 16 segments were averaged. Corrections were made for all gain and attenuation sources in the computation process and in the system to obtain a calibrated estimate of the power spectrum. We expressed the results in units of dB with respect to 1 microPascal squared per Hz, written dB//1uPa**2/Hz, and plotted graphs of the spectrum from 10 to 500 Hz, which are presented in the section on results. The spacing between frequency 'bins' in the spectrum is 1 Hz and the effective width of each bin is 1.7 Hz.

A similar process was followed to compute the spectrum up to 8 kHz. The sample rate was 16,384 sample/s, and 32 overlaping segments, each 1024 samples long, were processed and the results averaged. In the results, the spacing between frequency bins is 16 Hz and the effective width of each bin is 27.2 Hz.

It is useful to describe the sound level in a band of frequencies, which we call the 'band level'. We computed band levels by summing the spectrum results between selected frequency limits. In this report the bands used are 10-1000 Hz and 160-8000 Hz.

RESULTS

There are three aspects of the results: the background noise levels, the seismic signal levels, and the regression equations derived to model the received signal levels. We discuss these separately in this section.

Background Noise

Segments of the tape recorded data were analyzed between the received seismic signals to measure the background levels. We required 8.5 s, which was well within the 12 s between the seismic signals. Segments were selected near the beginning of the experiment and near the end, and analyses were performed for both the 9 and 18 m depths.

The averaged power spectra for the background at the beginning of the experiment are shown in Figure B-1. Spectra from 10 to 500 Hz and from 160 to 8000 Hz for the 9 m depth are shown on the left, and corresponding spectra for the 18 m depth are shown on the right. The dB scales are the same for the top two graphs (10-500 Hz), but there is a 10 dB offset between the graphs for 160-8000 Hz at the bottom. This is because the plotting program automatically scales the graph so the highest level in the spectrum falls within the top division, and the level at 160 Hz (which was the highest level for both graphs) was higher than 110 dB at 9 m and less than 110 dB at 18 m. The 9 m hydrophone, being closer to the hull of Northern Lighter, would be expected to have higher levels than the 18 m hydrophone. It is difficult to see from the graphs, but the level at the 9 m depth was slightly stronger, as can be seen from a comparison of the band levels in the following table:

Levels in dB//luPa

Freq band	**9 m**	**18 m**	**SS Zero**
10 - 1000 Hz	139	138	89
160 - 8000 Hz	133	132	81

For comparison, we have computed band levels for Knudsen's extended model for noise in a calm sea, 'Sea State Zero' (Knudsen et al. 1948). The level of noise in the water near the idling Northern Lighter is comparable to levels expected in a severe storm, although there is no reason to think Northern Lighter is noisier than other ships.

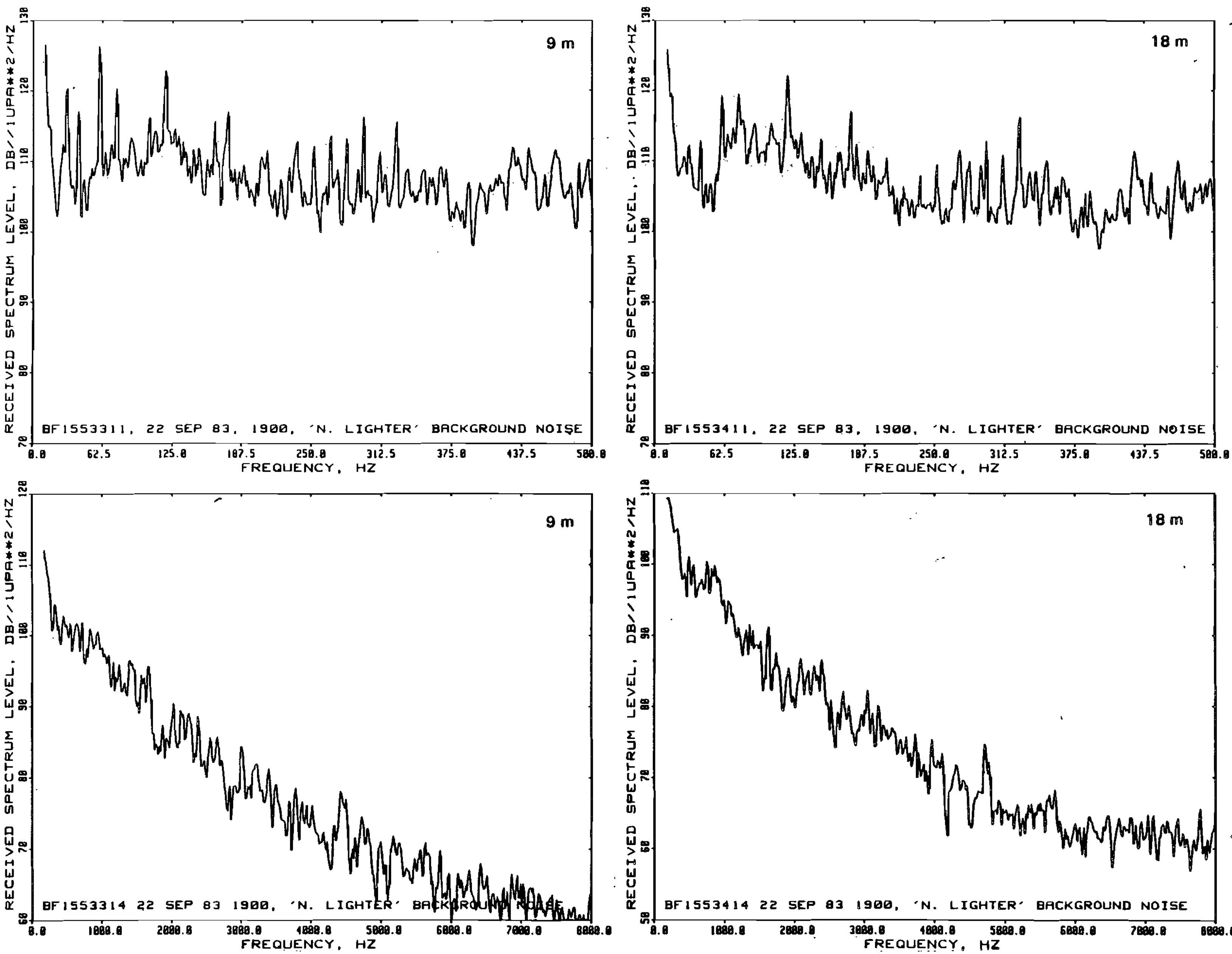


Figure B-1. Background noise spectra on Northern Lighter at depths of 9 and 18 m at the beginning of the seismic signal measurements.

Background noise spectra at the end of the experiment are presented in Figure B-2, which has the same format as Figure B-1. The band levels are presented in the following table:

	Levels in dB//1uPa	
Freq band	**9 m**	**18 m**
10 - 1000 Hz	138	135
160 - 8000 Hz	130	127

We have no reason to expect any change in the noise levels between the beginning and end of the test.

The character of the spectra in both figures reveals a significant number of tones, which appear as spikes in each spectrum. These tones are characteristic of sounds from rotating machinery such as engines, generators, pumps and the like, and we would expect the noise from Northern Lighter to be dominated by such tones.

Seismic Signals

As explained in the 'Methods' section, we analyzed the seismic signal levels using their waveforms. For example, signals from a range of 1.85 km are presented in Figure B-3 for depths 9 and 18 m. Although the signal is short relative to the 1 s time axis, we see a low frequency signal arriving before the large amplitude pulse and many noisy signals arriving afterwards. The low frequency signal has evidently traveled via a higher-speed path in the earth beneath the ocean. The large pulse is the water-traveling wave, and the noise-like signals following the large pulse are the results of sub-bottom reflections and perhaps reverberation in the water. All these signal components are interesting, but we will concentrate on the strong water wave as we assume this is the part, if any, most likely to affect marine mammals.

Figure B-4 is an expanded graph of the main pulses of the same signals shown in Figure B-3. The signal from the 9 m depth shows weak 'breaks' compared to the smooth oscillations in the signal from the 18 m depth. It is possible that these 'breaks' indicate slight overloading and distortion of the signal. When a signal was more severely distorted than appears in Figure B-4 we rejected it for consideration in deriving an equation for received signal level vs. range.

It is characteristic of sound propagation in shallow water that impulsive signals are received as the sum of many reflections from the surface and bottom

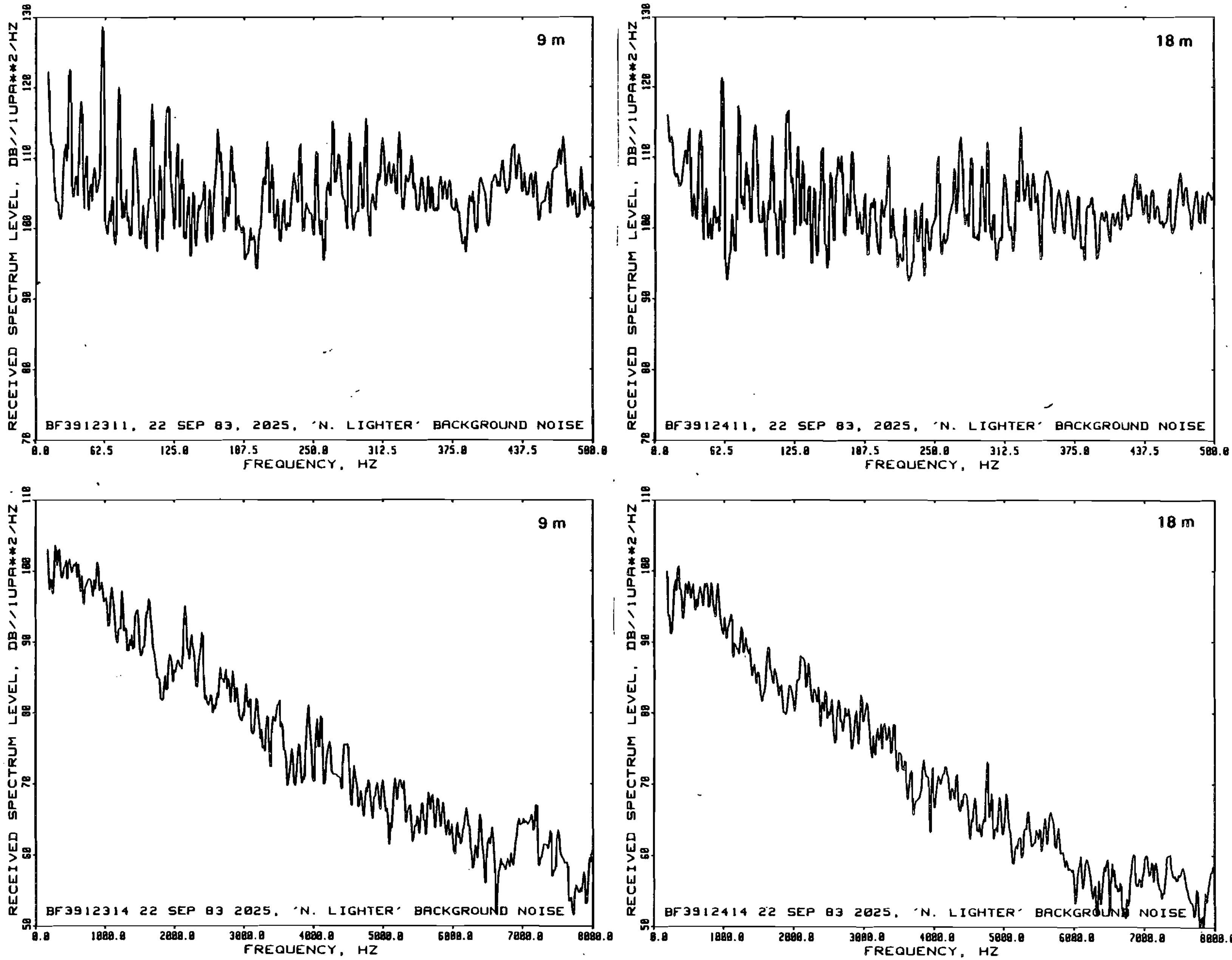
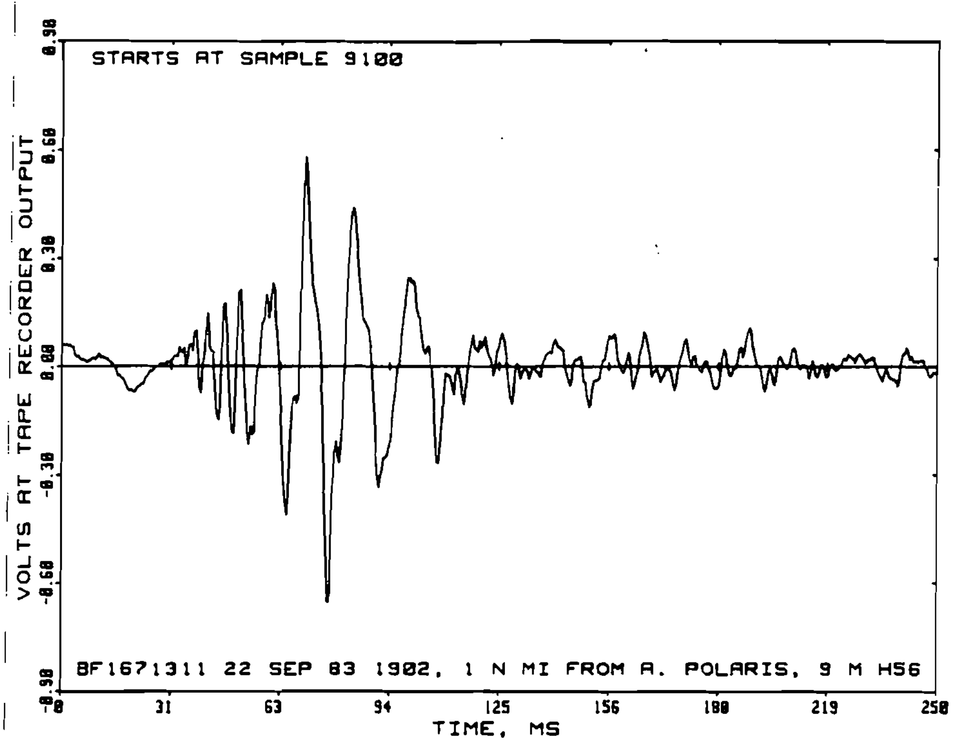


Figure B-2. Background noise spectra on Northern Lighter at depths of 9 and 18 m at the end of the seismic signal measurements.



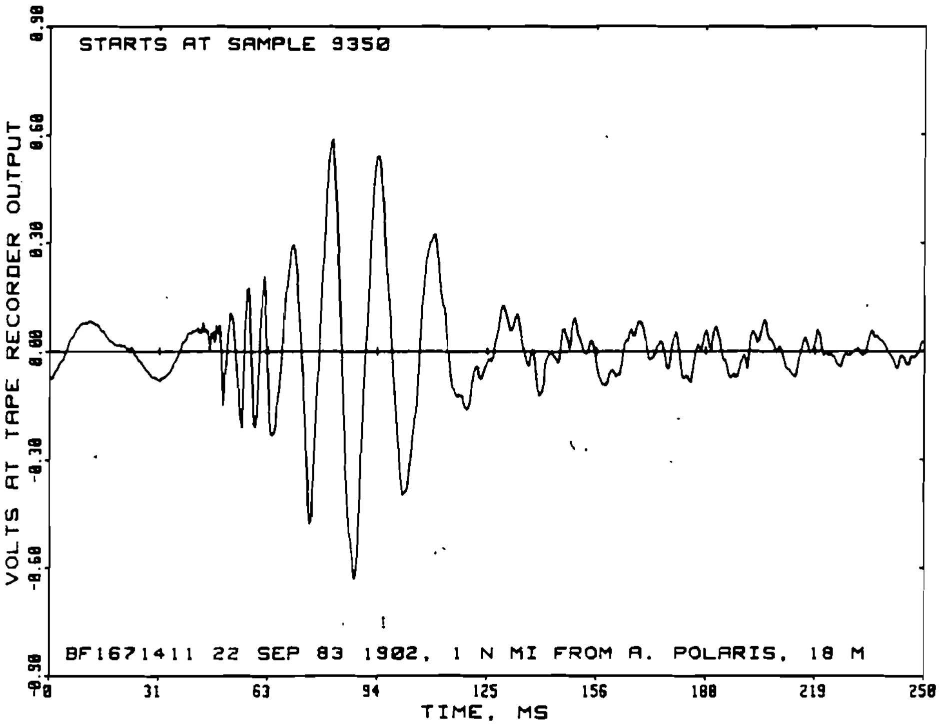
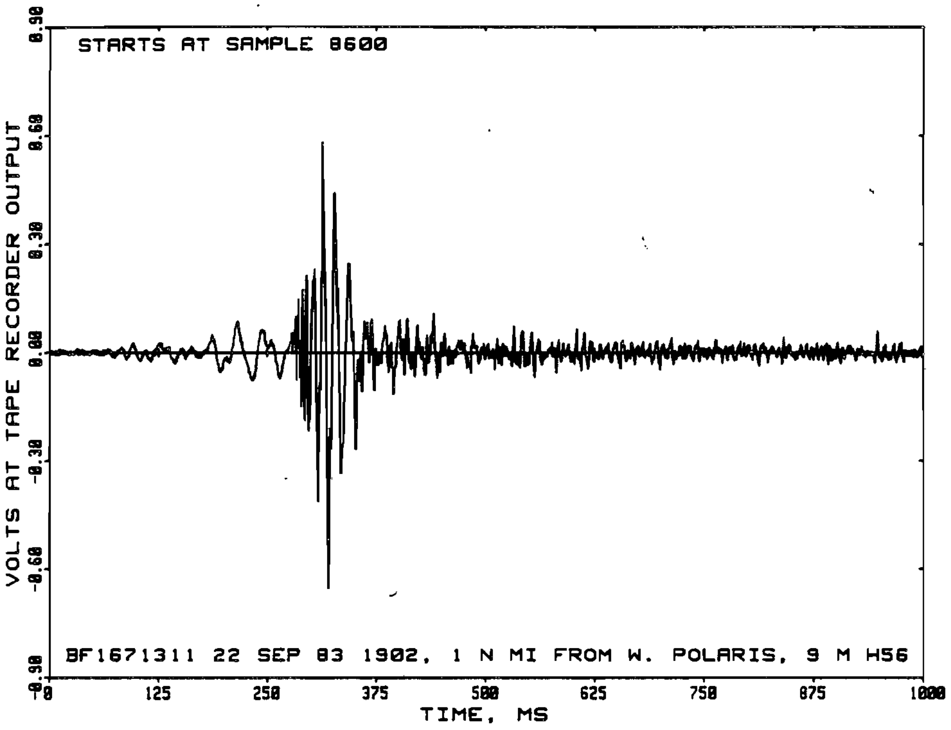


Figure B-3. Waveforms over a 1s period of a seismic signal from Western Polaris at range 1.85 km for hydrophone depths 9 and 18 m.



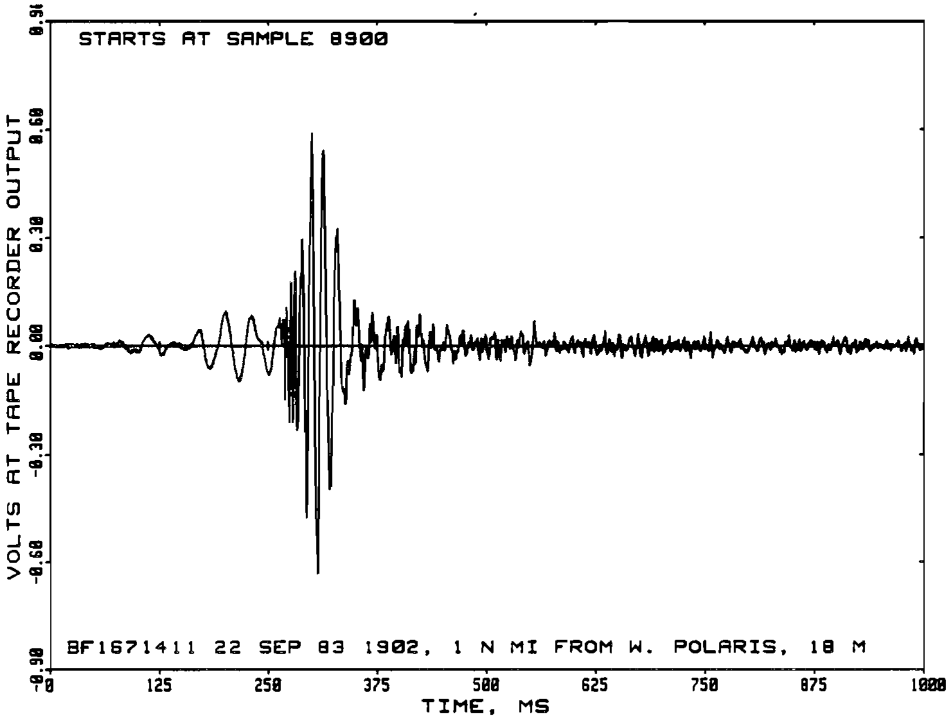


Figure B-4. The same waveforms in Figure B-3 expanded over a 250 ms period.

and that the pulse becomes 'stretched out' in time and appears to sweep from high frequencies to low. This effect is clearly visible in Figure B-4.

Figure B-5 portrays waveforms from 3.71 km. We note that the low frequencies evident in Figure B-4 (1.85 km) are still present. We found these frequencies to be on the order of 60-80 Hz. Figure B-6 portrays waveforms from 4.10 km on the same time scale (250 ms over eight divisions), and we note that the low frequencies have virtually disappeared. The remaining signals appear to be above 200 Hz. This rapid change in the signal frequency content, over a range change from 3.71 to 4.10 km, was unexpected.

Figure B-7 presents waveforms at depths of 9 and 18 m for seismic survey signals received when Western Polaris was 11.12 km away. Although still stronger than the noise, the signal-to-noise ratio is considerably lower than when the range was 1.85 km.

Regression Equations, Received Level vs Range

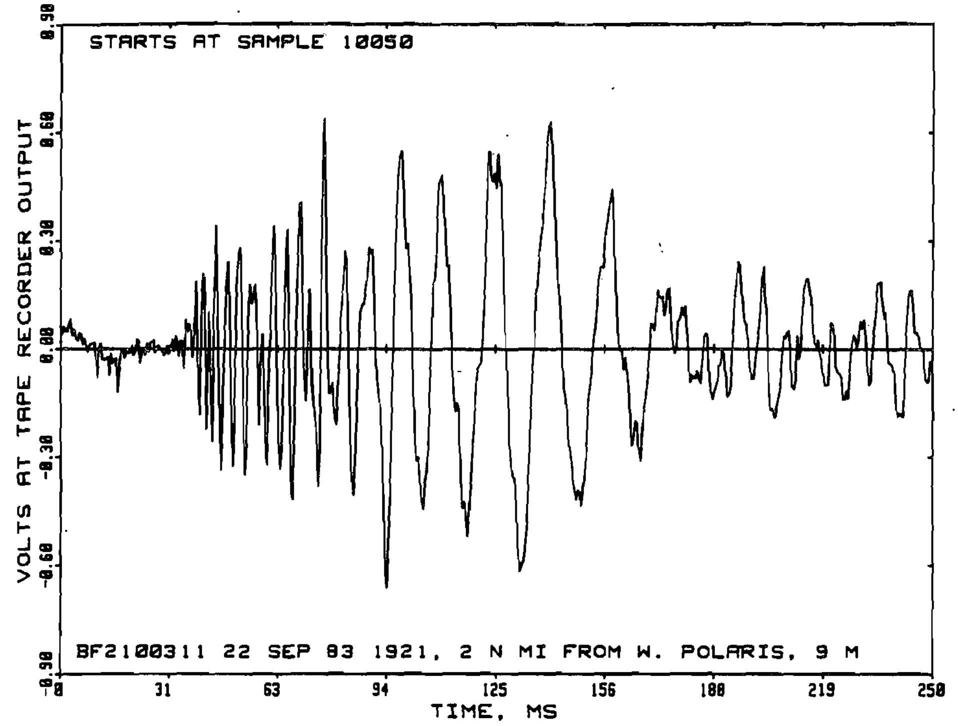
We experimented with many subsets of data and many forms of equations to relate received levels of seismic signals to range. In the Canadian Beaufort Sea, with water depths between 15 and 30 m, seismic signals from ranges between 8 and 28 km, and frequencies around 150 Hz, we found the equation

$$RL = 170.1 - 1.39\,R - 10\log(R) \qquad \text{Eq. (1)}$$

provided a good fit to the data, where RL is the received level in dB//1uPa and R is range in km (Greene, 1982, pp 313-320, 338). This was an agreeable result physically. We expected cylindrical spreading loss (10 log(R)) in shallow water and the 'R' term represented 1.39 dB/km loss due to aborption-like effects, which was certainly feasible. It seemed unwise to apply the equation to ranges much less than 5 km because of two effects at close ranges. One is that spherical spreading (20 log(R)) is expected near the source, and the second is that seismic signals are so large that finite amplitude effects must prevail at closer ranges and the propagation loss would be greater than one predicts from linear sound propagation.

The Northern Lighter data extend in range from 1.62 to 11.34 km. In water only 20 m deep we might have expected the spreading losses to become cylindrical before 1.6 km, but we had little idea about the extent of finite amplitude effects.

In a simple graph of all the data from both the 9 and 18 m depths, excluding measurements showing possible distortion, it appeared that results from the two



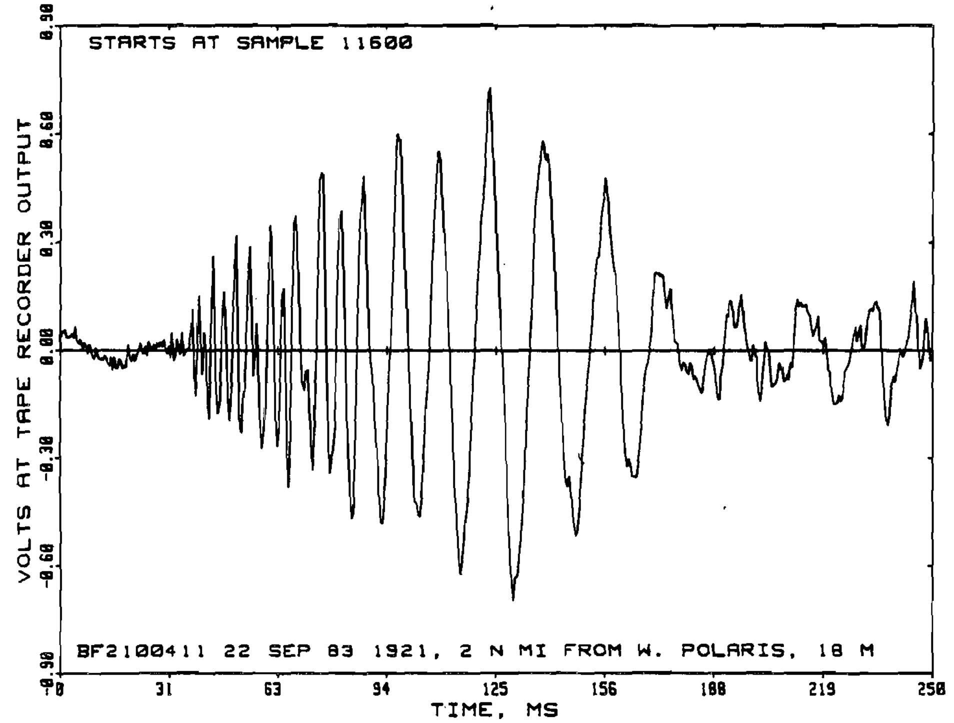


Figure B-5. Waveforms of a seismic signal from Western Polaris at range 3.71 km for hydrophone depths of 9 and 18 m.

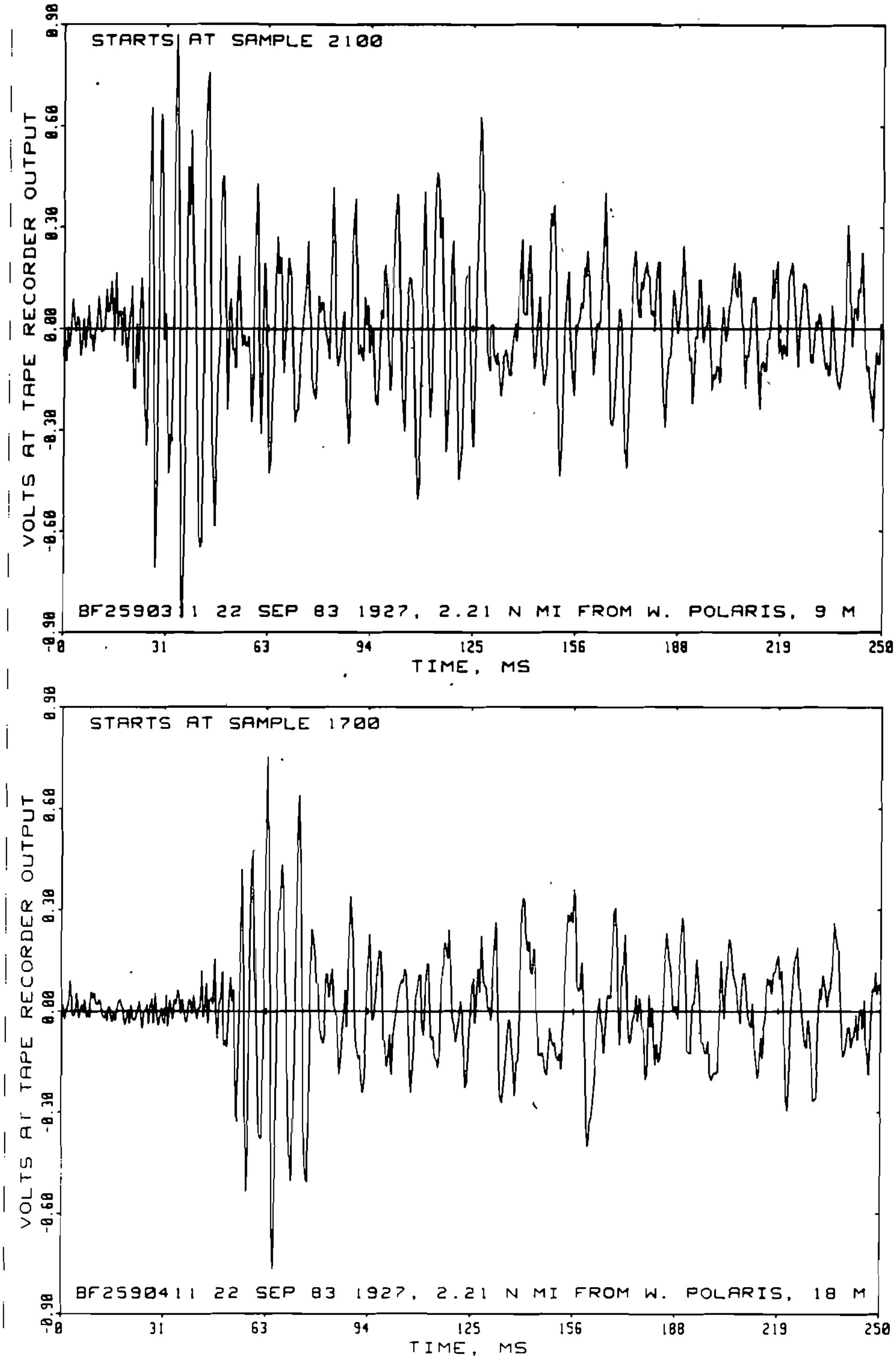
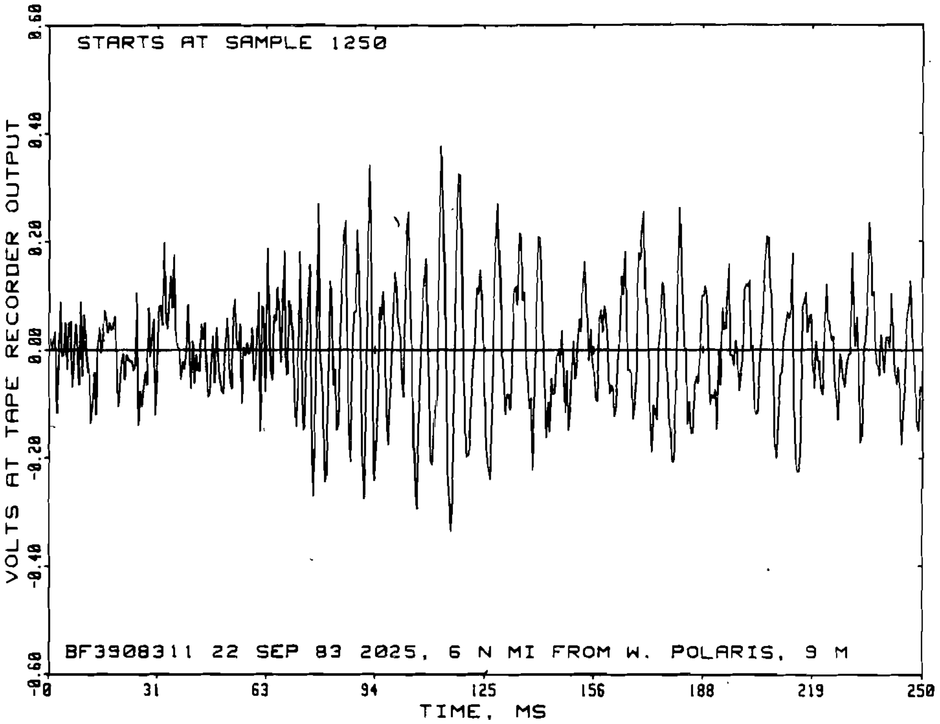


Figure B-6. Waveforms of a seismic signal from Western Polaris at range 4.1 km for hydrophone depth of 9 and 18 m. Note the loss of the low-frequency energy that had been strongly evident at the shorter ranges.



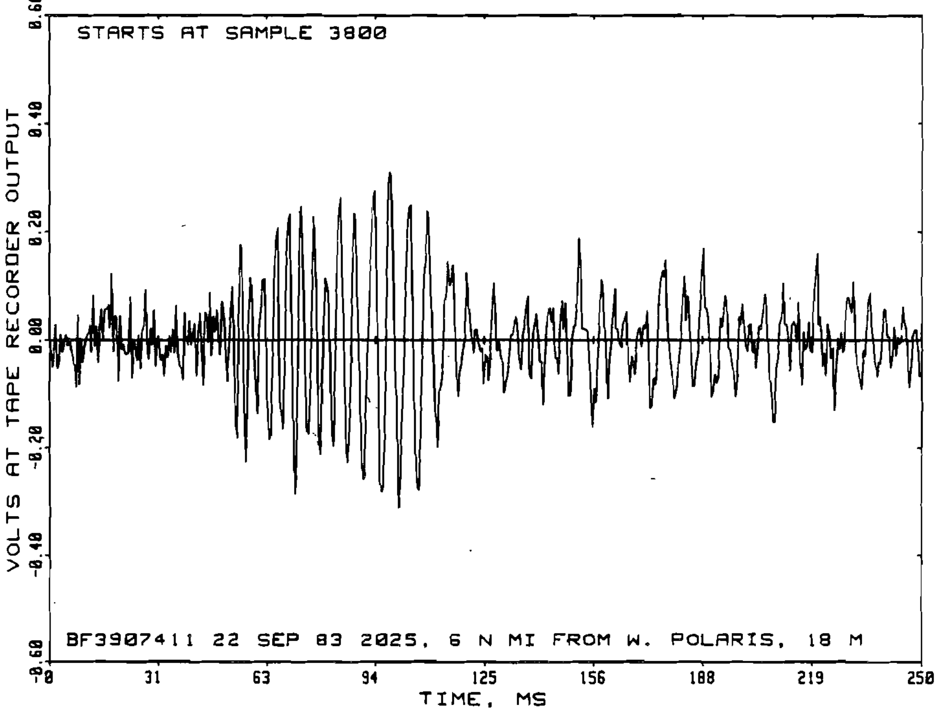


Figure B-7. Waveforms of seismic signals from <u>Western Polaris</u> at range 11.12 km for hydrophone depths of 9 and 18 m.

depths, although noticeably different, overlapped sufficiently to warrant considering them as one data set. We computed regression coefficients for the general equation

$$RL = \text{const} + \text{abloss}\ R + \text{sprloss}\ \log(R) \qquad \text{Eq. (2)}$$

where 'const' is the constant term that accounts for the source level and the transmission loss to the reference range, 'abloss' is the absorption loss coefficient and 'sprloss' is the spreading loss coefficient. The result was the equation

$$RL = 185.6 + 1.22\ R - 46.6\ \log(R)\ (\text{rho sq} = 0.924,\ n = 38) \qquad \text{Eq. (3)}$$

with standard error 2.6 dB. Although a reasonably good fit to the measurements, physically this was not a satisfactory result because the absorption loss coefficient was positive, providing a gain in received level of 1.22 dB/km. Regression coefficients for the data for 9 and 18 m depths separately were not too different.

We tried two other basic equations. One was in the same form as Equation (2) above but permitted the analyst to assign the spreading loss coefficient. To perform this type of regression required the spreading loss term to become part of the dependent variable, which presents a conflict because the spreading loss is range (independent variable) dependent. The coefficient of determination (rho squared) and the standard error have to be interpreted differently.

With cylindrical spreading a forced condition, the result was

$$RL = 177.8 - 1.8\ R - 10\ \log(R). \qquad \text{Eq. (4)}$$

This equation is similar to Equation (1) for the Canadian Beaufort Sea above. With spherical spreading a forced condition, the result was

$$RL = 179.9 - 0.97R - 20\ \log(R). \qquad \text{Eq. (5)}$$

This equation is plotted in the graph in Figure B-8, along with the 38 data points. The curve differs from the curve for Equation (3) above (not shown) in that the general equation is steeper at short ranges, passing closer to the 1.62 and 1.85 km

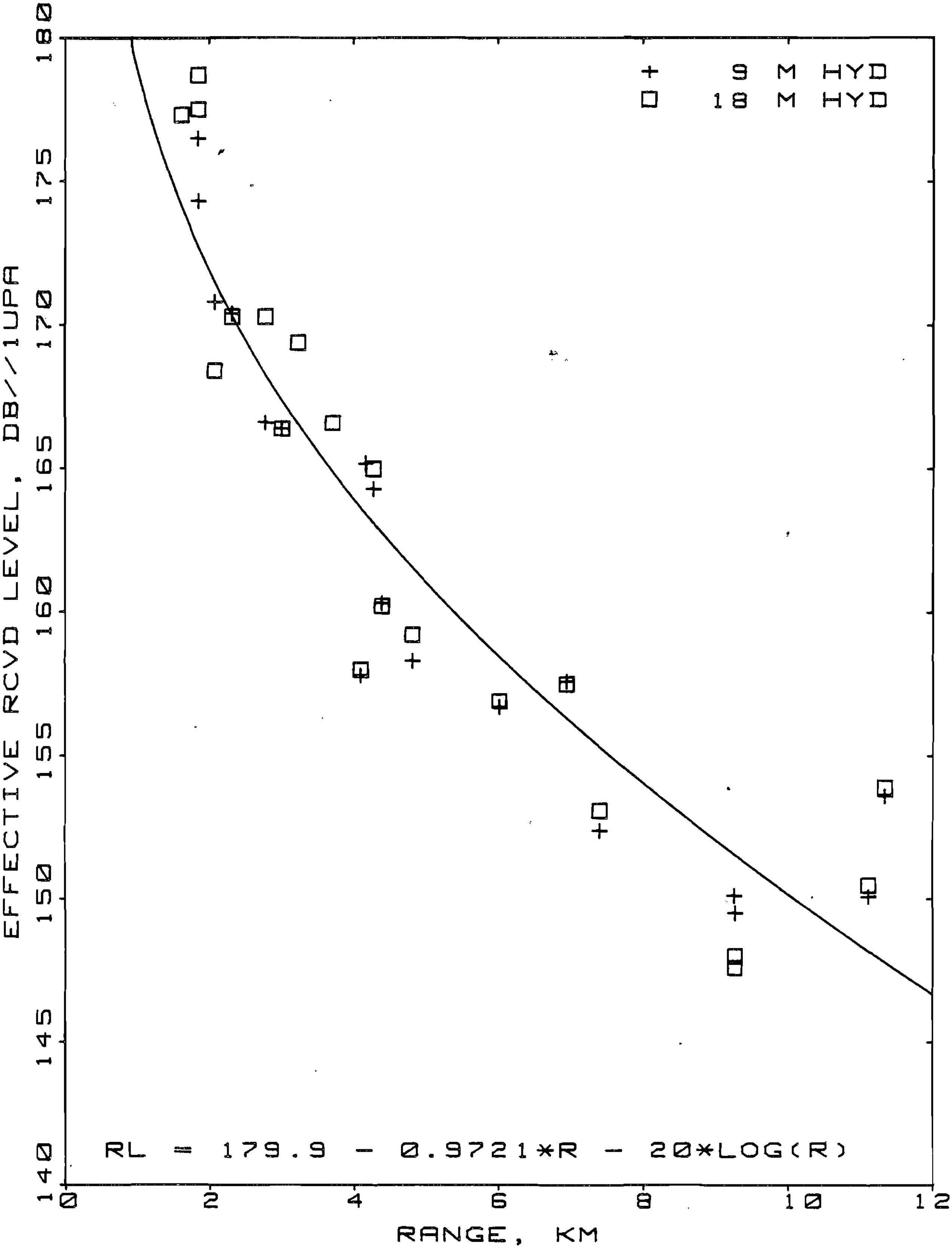


Figure B-8. Measured received levels and the regression-derived equation for received levels vs range including a range-dependent term and forced spherical spreading loss term.

points, and less steep at the long ranges, appropriate to the large spread in the measured received levels at 9.3 and 11.3 km.

The other basic equation tested involved only the spreading loss term. In effect, the absorption loss term was set to zero. The result for the 38 data points from depths of 9 and 18 m was Equation (6):

$$RL = 183.0 - 32.76 \log(R) \qquad \text{Eq.(6)}$$

with rho sq = 0.913 and standard error = 2.7 dB. The resulting curve is shown with the data points in Figure B-9.

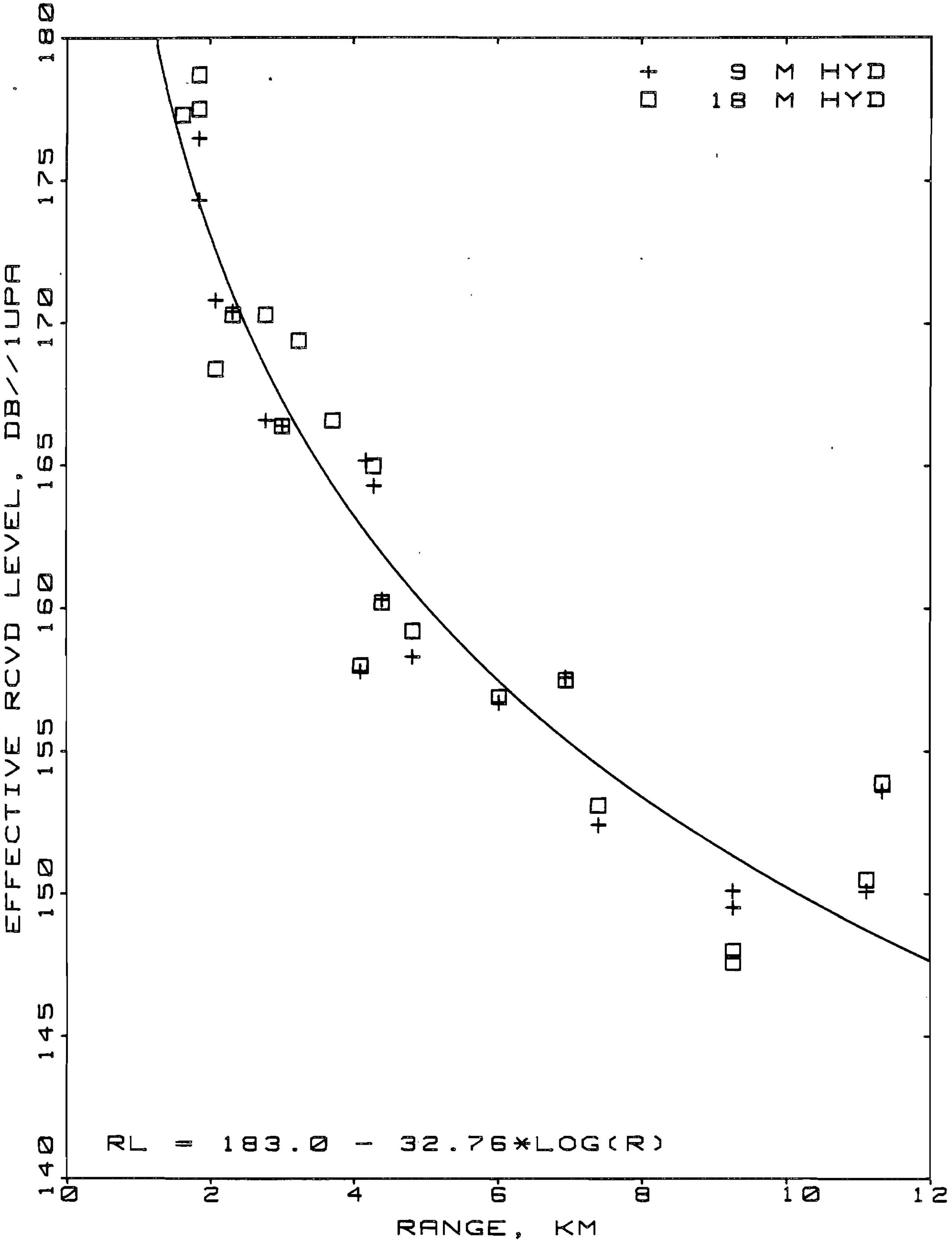


Figure B-9. Measured received levels and the regression-derived equation for recieved levels vs range for only a spreading loss term.

DISCUSSION

The results of the experiment reported here follow the general form expected for the transmission of seismic survey signals in the shallow waters of the Beaufort Sea. The questions raised may be related to higher-order effects than the simple geometrical spreading plus a combination of absorption and reflection losses used in a model equation. In the case of seismic signals in the Canadian Beaufort Sea over ranges between 8 and 28 km, a simple model for received signal level with only a spreading loss term (no range-dependent term), the result was -62 log(R). When the range-dependent term was added, a loss of 1.39 dB/km resulted and the spreading loss term became cylindrical, or -10 log(R). In the present case, the result with no range-dependent term was about -33 log(R), and we expected the addition of such a term would result in a modest loss per unit range and a reduced spreading loss coefficient. Instead, the range-dependent term was positive and the spreading loss coefficient increased in magnitude. However, when spreading loss was forced to be spherical, the range-dependent term was 0.97 dB/km. When cylindrical spreading was forced, the range-dependent term was 1.8 dB/km, not very different from the 1.39 dB/km found in the Canadian Beaufort.

It would be interesting to know what would have happened at longer ranges, as there was either an extraordinarily low received level from 9.27 km or an extraordinarily high received level from 11.12 km, or both. To check on these points we analyzed an additional signal at each of these ranges. The results were consistent.

There was a change in dominant frequency from 60-80 Hz for ranges up to 3.7 km to over 200 Hz for ranges above 4.1 km. We would not expect a change in the aspect of the source airgun array to account for this sudden change. Rather, it is likely to be the result of a sound propagation phenomenon having to do with the structure of the medium between source and receiver. Perhaps an ice floe interfered in some way.

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