NORTHSTAR MARINE MAMMAL MONITORING PROGRAM, 1996:

MARINE MAMMAL AND ACOUSTICAL MONITORING OF A SEISMIC PROGRAM IN THE ALASKAN BEAUFORT SEA

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National Marine Fisheries Service
Anchorage, AK, and Silver Spring, MD

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1. INTRODUCTION[1]

BP Exploration (Alaska) Inc. (BPXA) conducted an open-water seismic program in shallow waters of the central Alaskan Beaufort Sea during the 24 July through 19 September period of 1996. This region is occupied by ringed and bearded seals throughout the open water period, and small numbers of spotted seals also occur in the area. Bowhead and beluga whales migrate westward through the region in late summer and autumn, although their main migration corridors are offshore of the area of seismic exploration. Gray whales occur in the area only on rare occasions (LGL and Greeneridge 1996a).

Marine mammals might be disturbed by underwater sounds from the seismic exploration program. Bowhead whales usually show avoidance reactions to seismic vessels operating within several kilometers (Richardson et al. 1986; Ljungblad et al. 1988). Reaction distances may (or may not) be different for whales migrating past a relatively localized seismic operation like Northstar than in the circumstances previously studied. Previous monitoring studies have provided inconclusive results concerning avoidance at longer distances. However, there have been indications that some bowheads may show avoidance at distances as great as 24 km (Koski and Johnson 1987). Subtle behavioral reactions are suspected to extend to even longer ranges (Richardson et al. 1986; Richardson and Malme 1993). Reactions of gray whales to seismic exploration are similar (Malme et al. 1984, 1988). There are few published data on the reactions of either toothed whales or pinnipeds to open-water seismic exploration. However, given what is known about the hearing abilities of belugas and seals, they are expected to be able to hear seismic sounds, and may react to them (Richardson et al. 1995; Richardson and Würsig in press).

Inupiat whalers are especially concerned that seismic programs may displace some bowhead whales farther offshore, making them less accessible to hunters (Jolles [ed.] 1995; Rexford 1996). Based on their accumulated observations and experience, the Inupiat whalers also believe that whales exposed to seismic and other industrial noises are more "skittish" and difficult to hunt. These concerns were emphasized at a workshop entitled "Arctic Seismic Synthesis and Mitigating Measures Workshop", held in Barrow, AK, on 5-6 March 1997. Inupiat whalers believe that, during autumn migration, bowhead whales migrating west though the Alaskan Beaufort Sea can be displaced northward by as much as 30 miles from their normal migration corridor (Kanayurak et al. 1997).

One of the dominant considerations during the design of this monitoring project was the need to determine, insofar as possible, whether displacement of the bowhead migration corridor occurred during the Northstar seismic program. This study was designed to take into account both the results of previous scientific studies and the accumulated experience of the Inupiat whalers, both of which are useful in formulating hypotheses and study designs.

Whether seismic exploration sounds are strong enough to cause temporary or permanent hearing impairment in any marine mammals that might occur very close to the seismic source is unknown (Richardson et al. 1995:366). In part to avoid any such possibility, the

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National Marine Fisheries Service (NMFS) has concluded that baleen whales should not be exposed to seismic pulses with received levels above 180 dB re 1 µPa, and that pinnipeds and odontocetes should not be exposed to levels above 190 dB re 1 µPa (NMFS 1995).

1.1 Incidental Harassment Authorization

Behavioral disturbance to marine mammals is considered to be "take by harassment" under the provisions of the Marine Mammal Protection Act (MMPA). Such disturbance falls within the MMPA definition of Level B harassment, which entails "disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering". "Taking" of marine mammals without special authorization is prohibited. However, under the 1994 amendments to the MMPA and regulations finalized in 1996, "citizens of the United States can apply for an authorization to take incidentally, but not intentionally, small numbers of marine mammals by harassment" (NMFS 1996). Incidental Harassment Authorizations (IHAs) can be issued if the "taking will have a negligible impact on the species or stock(s) of marine mammals and will not have an unmitigable adverse impact on the availability of the species or stock(s) for subsistence uses". IHAs can authorize Level B harassment (disturbance). Because of the possibility that the planned Northstar seismic program might disturb marine mammals, BPXA applied in March 1996 for an Incidental Harassment Authorization to cover the 1996 Northstar seismic project.

The IHA process does not authorize injurious or lethal takes of marine mammals. To minimize the possibility that marine mammals close to the seismic source might be exposed to levels of sound high enough to cause hearing damage or other injuries, the IHA application included proposals for a marine mammal monitoring program and for shutdown of the seismic source when mammals were seen within designated "safety radii". BPXA's application for an IHA proposed to shut down the airguns if seals were detected within 150 m, or if cetaceans were detected within 650 m. The rationale is described under "Shutdown Criteria" on page 2-14. The IHA application also included provision to measure actual sound levels vs. distance prior to the start of the whale migration season. This would allow the "shutdown radii" to be adjusted, if appropriate.

A draft monitoring plan prepared by LGL Ltd. and Greeneridge Sciences Inc. for BPXA was submitted to NMFS in March 1996 with the IHA application. The proposed monitoring program was reviewed by NMFS, by representatives of the subsistence hunters in northern Alaska, and by outside experts during the spring of 1996. An amended monitoring plan was prepared in June 1996 taking these comments into account. In addition, a "Conflict Avoidance Agreement" was negotiated between BPXA, the Alaska Eskimo Whaling Commission, and the Whaling Captains' Associations of the villages of Nuiqsut and Kaktovik. On 18 July 1996, NMFS issued an Incidental Harassment Authorization to BPXA for the 1996 Northstar open-water seismic program.

The IHA (as amended) required submission of a preliminary report on sound measurements prior to 1 September 1996, a report on the results of the monitoring work within 90 days after the end of the field program, and a draft final report by 1 April 1997. The preliminary sound measurement report was submitted to NMFS on 30 August. Based on those measurements, it was agreed by BPXA and NMFS that the pinniped and cetacean "safety radii" applicable to the array of airguns should be increased from 150 and 650 m, respectively, to 250 and 750 m. This change was implemented on 30 August.

1.2 Objectives

Three different but related sets of objectives have been specified for this monitoring project. (1) The monitoring plan identified a set of field tasks that needed to be met. (2) A meeting of a peer review group in Seattle on 21 May 1996 identified eight analytical objectives that should be addressed. (3) The Incidental Harassment Authorization issued by NMFS identified various reporting requirements.

Field Tasks Identified in Monitoring Plan

The tasks to be addressed by the 1996 Northstar marine mammal monitoring program, as listed in the final monitoring plan dated 11 June 1996, were as follows:

- provide qualified marine mammal observers for the seismic source boat(s) throughout the seismic exploration period in 1996, to monitor the occurrence and behavior of marine mammals near the seismic source during daytime and nighttime periods when it is and is not operating, fulfilling the monitoring and mitigation conditions of the IHA and other permits; night vision devices would be used at night;
- conduct an aerial monitoring program from 1 September 1996 until seismic work ends to monitor the distribution, movements and general activities of bowheads and other marine mammals in and near the Northstar Unit;
- exchange 1996 aerial survey data with MMS, as agreed between BPXA and MMS;
- conduct a vessel-based acoustics program for ~10 days in late August 1996 to obtain systematic measurements of seismic sounds, propagation loss, and ambient noise;
- drop sonobuoys during the aerial survey program after 1 September to collect data on (a) ambient noise and (b) seismic exploration noise. Sonobuoys would provide noise data at more places and times, and under more environmental conditions, than possible from the vessel, including ambient and seismic data from bowhead locations;
- deploy bottom-mounted acoustic recording devices at several locations east of and offshore of the Northstar region to obtain near-continuous records of underwater noise and whale calls in those areas from 1 September to the end of the seismic program (or until ice precludes data retrieval);
- update the 1995 evaluation of marine mammal use of the area [LGL and Greeneridge 1996a] to take account of the BPXA/LGL and MMS visual and acoustic results from 1996, and evaluate the effects of the 1996 seismic program on the distribution and movements of bowhead whales;
- prepare the "90 day report" on the monitoring and estimated "take by harassment", and a subsequent comprehensive report on all aspects of the 1996 work.

All of the general field objectives were met in whole or in part.

Analysis Objectives Identified by Peer Review Group

Eight analysis objectives were identified at a meeting held in Seattle on 21 May 1996 to review the draft monitoring plan:

a. "Estimate the proportion of the bowhead whales (and other marine mammals) that migrate past the Northstar study site within 20 nm of the northern edge of the site when the air guns are in operation." [Results are in section 5.3.8, "Estimated Bowhead Take by Harassment".]

b. "Estimate the number of other marine mammals within 20 nm of the northern edge of the study site when the air guns are in operation." [For belugas, see §5.5.]

c. "Estimate the number of baleen whales within 2130 ft of the sound source when the air guns are in operation." [See §5.3.8.]

d. "Estimate the number of other marine mammals within 500 ft of the sound source during seismic operations." [For seals, see §4.5.]

e. "Estimate the distribution of observed distances between the (closest) active seismic vessel and bowhead whales seen on effort during the aerial survey." [See §5.3.2, "Distribution" and Table 5.3.]

f. "Test the hypothesis that the distribution of bowhead whales (and other marine mammals) is independent of the estimated received sound level produced by all of the vessels associated with the Northstar study." [See §5.3.3, "Distance from Shore".]

g. "Test the hypothesis that the swimming direction of bowhead whales is independent of the estimated received sound level produced by all of the vessels associated with the Northstar study." [See §5.3.4, "Behavior and Headings".]

h. "Test the hypothesis that vocalization rates of bowhead whales are independent of the estimated received sound level produced by all vessels associated with the Northstar study (using some type of remote data collection system)." [See §3.8, "Whale Calls" and §5.3.6, "Bowhead Call Counts".]

Reporting Requirements Specified in the IHA

The Incidental Harassment Authorization issued by NMFS on 18 July 1996 included the following requirements for the "90 day report" and final report:

1. Dates of the seismic survey from start to termination. [See Chapter 2.]
2. Specifications of the survey including, but not limited to, a description of the seismic array, total power output, number and length of seismic track lines, number of seismic vessels (if more than one at one time), etc. [See Chapter 2.]
3. Results of the vessel monitoring program, including: (a) Information on the numbers (by species) of marine mammals observed during the survey; (b) the estimated number of marine mammals (by species) that may have been harassed as a result of the seismic array either through noted behavioral change or because the animal was within its designated zone of potential harassment (bowhead, gray and beluga

whales—160 dB isopleth; seals—190 dB); (c) marine mammal behavior patterns observed within the 160 dB isopleth whenever the seismic source is off (speed, direction, submergence time, respiration, etc.); and (d) any behavioral responses or modifications of these behavioral indicators due either to the seismic array's or vessel's noise. [See Chapters 4 and 5.]

4. Aerial survey data from the BPXA and MMS surveys in and near the Northstar Unit must be analyzed and summarized for bowhead distribution, movement patterns (spatial and temporal), abundance indices and estimated numbers in the area during 1996. [These data are] to be compared with data collected previously. [See §5.3.2, "Bowhead Whale/Distribution".]
5. Results of any research conducted on the effects of seismic airgun noise on marine mammals, including any measurements made of attenuation rates. [Acoustic data are in Chapter 3.]

1.3 Report Organization

The present document constitutes the final technical report on the monitoring work. It is an expanded version of the "90 day report" submitted to NMFS, the Alaska Eskimo Whaling Commission (AEWC) and the North Slope Borough (NSB) in December 1996 (LGL and Greeneridge 1996b). This final report contains additional data and updated analyses. It takes account of comments from the AEWC and the NSB concerning the "90 day report". It also takes account of comments received from NMFS, AEWC, NSB and MMS at a review meeting held in Seattle on 16-17 July 1997. This final report supersedes the "90 day report".

The present report includes four main chapters describing the following:

- the 1996 Northstar open-water seismic program (Chapter 2);
- the physical acoustics measurement program (Chapter 3);
- the results of monitoring for seals, and the estimated numbers of seals "taken by harassment" (Chapter 4); and
- the results of monitoring for whales, and the estimated numbers of whales "taken by harassment" (Chapter 5).

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2. SEISMIC PROGRAM DESCRIBED[1]

2.1 Introduction

The Northstar seismic program in 1996 consisted of an Ocean Bottom Cable (OBC) seismic survey in nearshore waters of the central Alaskan Beaufort Sea. This work was conducted from 24 July through 19 September 1996 with an airgun array consisting of eleven 120 in^3 Bolt airguns totalling 1320 in^3 when all guns were used. Testing of the airgun array began on 24 July; production operations began on 27 July and continued until deteriorating ice and weather conditions forced an end to airgun operations on 18 September. Most work was conducted in and near the Northstar region, including waters from Prudhoe Bay West Dock out to about 45 km northwest of West Dock, and from the barrier islands out to as much as 13 km offshore of the barrier islands (depths up to about 55 ft or 17 m; see Fig. 2.2-2.5, later). However, initial work from 24 July until 8 August 1996 was east of Prudhoe Bay in waters east of the Endicott Development (depths 10-25 ft or 3-8 m).

This project was different from previous open-water seismic programs in the Beaufort Sea in that the Ocean Bottom Cable (OBC) method was employed. The area to be surveyed was divided into patches, each approximately 5.9 km by 4.0 km in size. Within each patch, six receiving cables were placed on the bottom parallel to one another. Seismic data for each patch were acquired by towing the airgun array along a series of 27 source lines, each 7.3 km long, oriented perpendicular to the receiving cables. While seismic data acquisition was underway on one patch, the cable deployment vessels normally were laying cables in the patch that was to be surveyed next, and/or in retrieving cables from the patch where surveys had just been completed. During the 1996 program, seismic data were acquired from all or parts of 16 patches: four patches east of Endicott and 12 patches in or near Northstar.

Overall, a total of about 2946 km of production seismic survey was shot. Of this, 1135 km was shot during the period 1-18 September when it was likely that bowhead whales would be in the area. This production shooting occupied an estimated total of 355 hours, of which 126 h were in September. Also, a single 120 in^3 airgun was used for an additional 98 h and 834 km, of which only 9 h and 77 km were in September; this single-gun work was done to calibrate the locations of receiving cables. Finally, one or more airguns were operated during many line changes. Line changes occupied 164 h, of which 42 h were in September.

Marine mammal monitoring personnel were aboard the source vessel throughout the period of operations. They watched for marine mammals at all times (day and night) while airguns were operated, and helped implement the provisions of the Incidental Harassment Authorization (IHA) that had been issued to BPXA by the National Marine Fisheries Service (NMFS). They also conducted watches during selected periods when the airguns were not firing. A large number of seals, but no whales, were seen from the source vessel. When seals

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were seen within the "safety radius" specified in the IHA, the airguns were immediately shut down. As described on page 1-2, the designated safety radius for seals was 150 m up to 30 August. Based on sound propagation measurements done at Northstar during August (see Chapter 3) and on discussions with NMFS, the safety radius for seals was increased—effective on 30 August—to 250 m for times when >1 airgun was in use. The safety radius remained 150 m during single-airgun operations.

The following subsection provides additional details about the equipment used for the seismic program and its mode of operation, insofar as these are relevant to marine mammal monitoring and mitigation. A subsequent subsection summarizes the marine mammal monitoring and mitigation procedures. Measurements of the underwater sounds propagating horizontally from the seismic operation are given in Chapter 3 on PHYSICAL ACOUSTICS MEASUREMENTS. Results of marine mammal monitoring and estimates of numbers of marine mammals "taken by harassment" are given in Chapters 4 and 5 on SEALS and WHALES, respectively.

A variety of metric and non-metric measurement units are used in this Chapter. Metric units are usually used for distances, but maps also show a nautical mile scale. Non-metric units are used if they were referenced in the associated study objective. Non-metric units are also used when they are the units usually used in describing equipment or procedures.

2.2 Equipment and Operations

Vessels Used

The vessels used for the 1996 Northstar OBC program were the following:

Source vessel	*Point Barrow* 32 x 90 ft Point Class tugboat, used to tow airgun array; also the platform from which vessel-based marine mammal observers watched for marine mammals. *Point Barrow* had 8-10 ft draft and two Caterpillar 3512 diesel engines totaling 2100 hp, each engine driving a 4-bladed stainless steel propeller in a Kort nozzle. Three 8000 lb compressors provided compressed air for the airgun array.
Telemetry/Camp Barge	R/V *Arctic Endeavor* 90 x 210 ft ice-resistant barge with 78-person camp; data from the OBCs were received and recorded here. Anchored in or near patches where work was underway; periodically moved to new work area by tug. Had four generators with Caterpillar D-353 engines rated at 350 kW each; two generators were normally in operation.

Cable barge	Barge 216 60 x 200 ft deck cargo barge; primary platform for cable deployment and retrieval; carried spill response trailer, 25 kW generator; pushed by tug *Sag River*.
Support tug	*Sag River* 27 x 64 ft Lighter Class tug, used to move the cable barge (Barge 216). Powered by three D-343 Caterpillar diesels totaling 1095 hp, with each engine driving a four-bladed stainless steel propeller; no nozzles. Draft 3-5 ft.
Cable tug	*Toolik River* 27 x 64 ft Lighter Class Tug, used from 6 September onward for cable deployment and retrieval. Specifications same as for *Sag River*.
Crane barge	Barge 215 60 x 200 ft deck cargo barge; Manitowoc 4600 S-4 350 ton crane.
Battery/cable handling	*Peregrine Falcon* 17 x 72 ft jet-driven aluminum landing craft; used to deploy, retrieve and charge 250-lb batteries; assisted in cable deployment and interconnection. Powered by three Cummings diesels, 300 hp each, driving Kodiak model 403 jets. Draft 28 inches.
Sea taxi/Acoustic research	*La Brisa* 14 x 59.5 ft jet-driven charter vessel; used for crew changes, support of boat-based acoustic measurements, and (in September) deployment of Digicourse system to determine locations of OBCs. Powered by three Volvo Pinta diesels of 380 hp each, driving Doran 13 inch jets. Draft 3 ft; 5000 lb crane; 12 kW diesel electric generator.
Cable LCM-6	*Faraday* 14 x 56 ft landing craft; supplementary cable deployment/ retrieval vessel; used early in the season.
Source LCM-6	*Hippo* 14 x 56 ft landing craft; intended as supplementary source vessel, but not used.

Ocean Bottom Cables

For each patch, the cable layout consisted of six 5.9-km cables laid parallel to one another with spacing of 660 m. In most patches the cables were oriented 300°-120° True (Fig. 2.1). Receiving hydrophones were attached at frequent intervals along the cables. Cables were deployed or retrieved by Barge 216, LCM *Faraday*, or tug *Toolik River* as the vessel moved along the desired line. *Peregrine Falcon* was used to deploy and retrieve the required

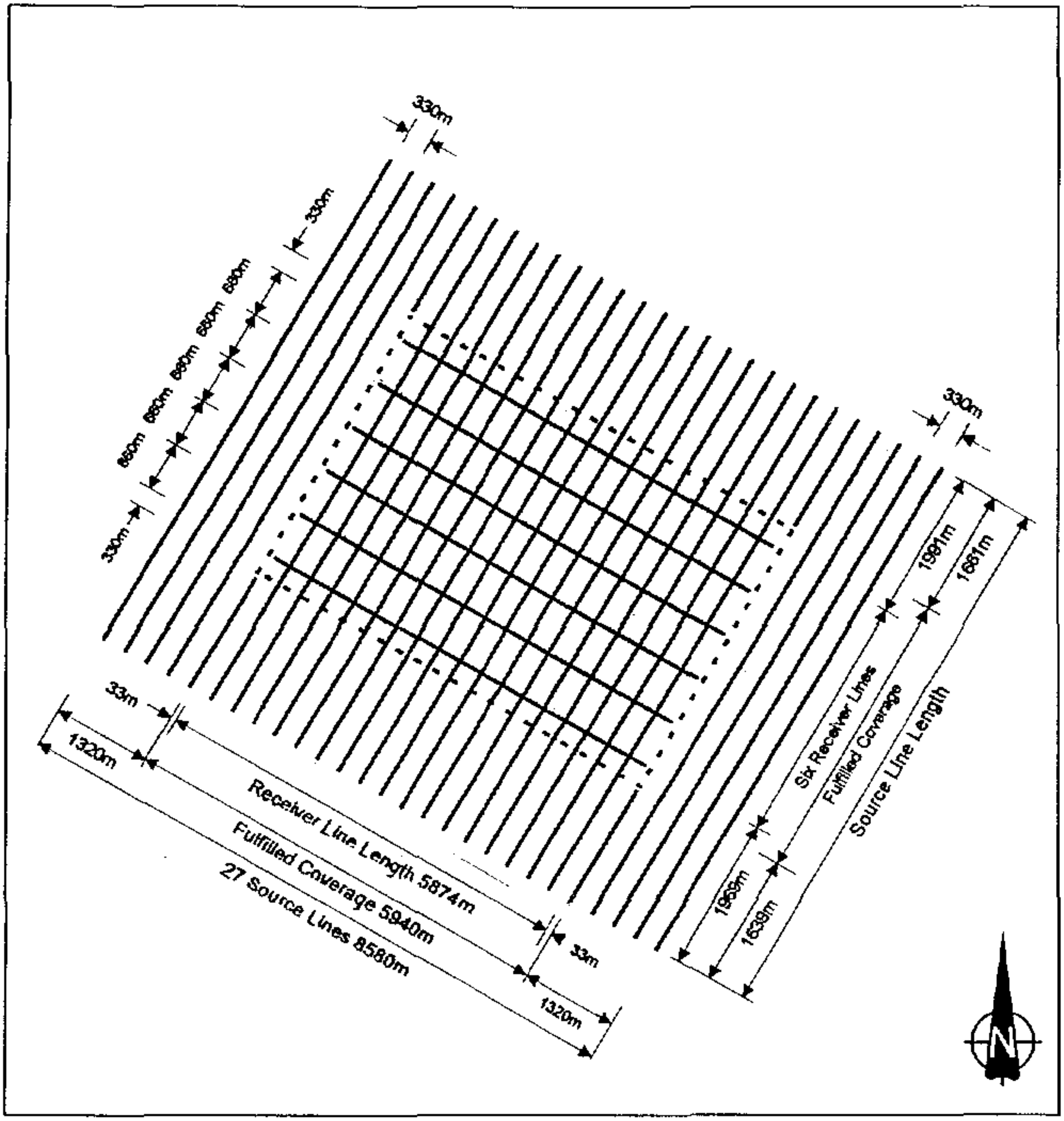

FIGURE 2.1. Configuration of the 27 source lines and 6 receiver cables for a standard patch during the 1996 Northstar OBC seismic survey. The dashed rectangle shows the outline of one patch (5.9 x 4.0 km). The 27 source lines cover an area of 8.6 x 7.3 km. Source lines for each patch extend into adjoining patches. The source lines are oriented 030°-210° True; the receiver cables are oriented 300°-120° True.

batteries, and to establish necessary electrical connections. Data received by the hydrophones were transferred to the telemetry barge (*Arctic Endeavor*) for recording.

Source Vessel

The tug *Point Barrow* was used as the source vessel throughout the program. For each patch, it operated along a series of 27 source lines oriented perpendicular to the OBC receiving cables. As the cables were usually oriented 300°-120° True, most source lines were oriented 210°-030° True. The standard length of each source line was 7.3 km, and the lines were spaced 330 m apart to cover a total area of 7.3 km by 8.6 km approximately centered on the grid of receiving cables (Fig. 2.1).

The *Point Barrow* towed an airgun array system consisting of 11 Bolt 1900LX airguns, each of 120 in^3, usually firing every 44 meters (166 shots per 7.3 km source line). All of the active guns were fired simultaneously. The *Point Barrow* typically travelled at about 4 to 5 knots, covering a 7.3-km source line in just under one hour with the interval between shots usually being 15-18 seconds. During the initial several days of the program, shots were fired every 22 m (331 shots per 7.3 km source line), but the speed of the vessel was generally lower.

Production operations between 27 July and 18 September 1996 totalled 2946 km and 355 hours, of which 1135 km and 126 hours were during September. These figures do not include line changes.

Line changes required widely varying amounts of time, depending on whether lines were shot in order, and whether pauses for maintenance, crew changes, or other activities were necessary. A subset of the airguns, usually 4 to 6, sometimes continued to fire during line changes in order to avoid the need for gradual "ramping up" to full power at the start of the next line (see Mitigation, below) and/or for operational purposes. Line change operations totalled 164 hours (42 h in September); this includes the extended periods when other activities were done during line changes. At those times, shooting was often interrupted.

The characteristics of the airgun array are described in more detail in Chapter 3 on PHYSICAL ACOUSTICS MEASUREMENTS (§3.3).

Ocean Bottom Receiver Localization (OBRL)

One of the methods used to verify the exact positions of the receiver cables on the ocean bottom entailed the use of a single airgun for Ocean Bottom Receiver Localization (OBRL). OBRL was done by traveling along each side of each receiver line at an offset distance of about 150 m while firing one airgun, normally at intervals of 22 m (about one shot every 8 s). Up to 12 OBRL lines (two per cable) were run per patch, generally while the patch was being laid out and before the start of production shooting with the full airgun array. Later in the season, there was increasing reliance on alternative methods of position-finding. OBRL was done on 17 dates in late July and August, but on only two dates in September (1 and 9 September). OBRL shooting totalled 834 km and 98 hours (not counting line changes), of which 77 km and 9 hours were in September.

Interruptions by Ice and Weather

Drifting ice caused considerable complications in deploying and retrieving cables, and sometimes damaged cables that were on the bottom. Late in the season, newly-forming ice caused further difficulties. The presence of ice strongly affected where operations were possible on any given date, and sometimes interrupted the program. There were four periods when heavy seas or ice (sometimes combined with other problems) resulted in suspension of airgun operations for extended periods:

- from 19 August (afternoon) to 22 August (early morning);
- from 25 August (evening) to 30 August (evening), except for some test shooting the afternoon of 29 August;
- from 1 September (mid-day) to 3 September (early morning); and
- from 4 September (late afternoon) to 9 September (early morning).

Cable laying and/or cable retrieval continued during some of these times. There were many shorter periods when airgun operations were interrupted because of weather, ice, or operational considerations.

Navigation and Vessel Movements

Locations of all primary vessels were determined within an accuracy of a few meters by Differential GPS receivers. These locations were transmitted by telemetry to the telemetry barge (*Arctic Endeavor*). A real-time map display of vessel locations and other relevant data was used to assist in managing the operations. Positions of the source vessel and airgun array were logged for every airgun shot, along with water depth and other information about the shot. In addition, at most times during the season, positions of all vessels were logged in digital files every 5 minutes to allow retrospective mapping of vessel movements.

Prior to 8 August, operations were centered east of Prudhoe Bay. From 8 August onward, operations were northwest of Prudhoe Bay. Within the latter period and area, operations moved generally westward as the season progressed. Figures 2.2 and 2.3 show the movements of the airgun source vessel and other project vessels during the middle part of the seismic program, from 15 to 31 August. Within this period, movements during different weeks are shown with different colors. Figures 2.4 and 2.5 show similar data for September. The maps of source vessel movements show all positions logged for *Pt. Barrow*, including times when the airguns were and were not operating. For example, the airguns were not operating when *Pt. Barrow* was used for an ice reconnaissance to the northeast on 7 September (Fig. 2.4). In general, the airgun array was in use whenever *Pt. Barrow* was traveling NNE-SSW or N-S along grid lines. A single airgun was in use for OBRL when *Pt. Barrow* was traveling WNW-ESE along grid lines.

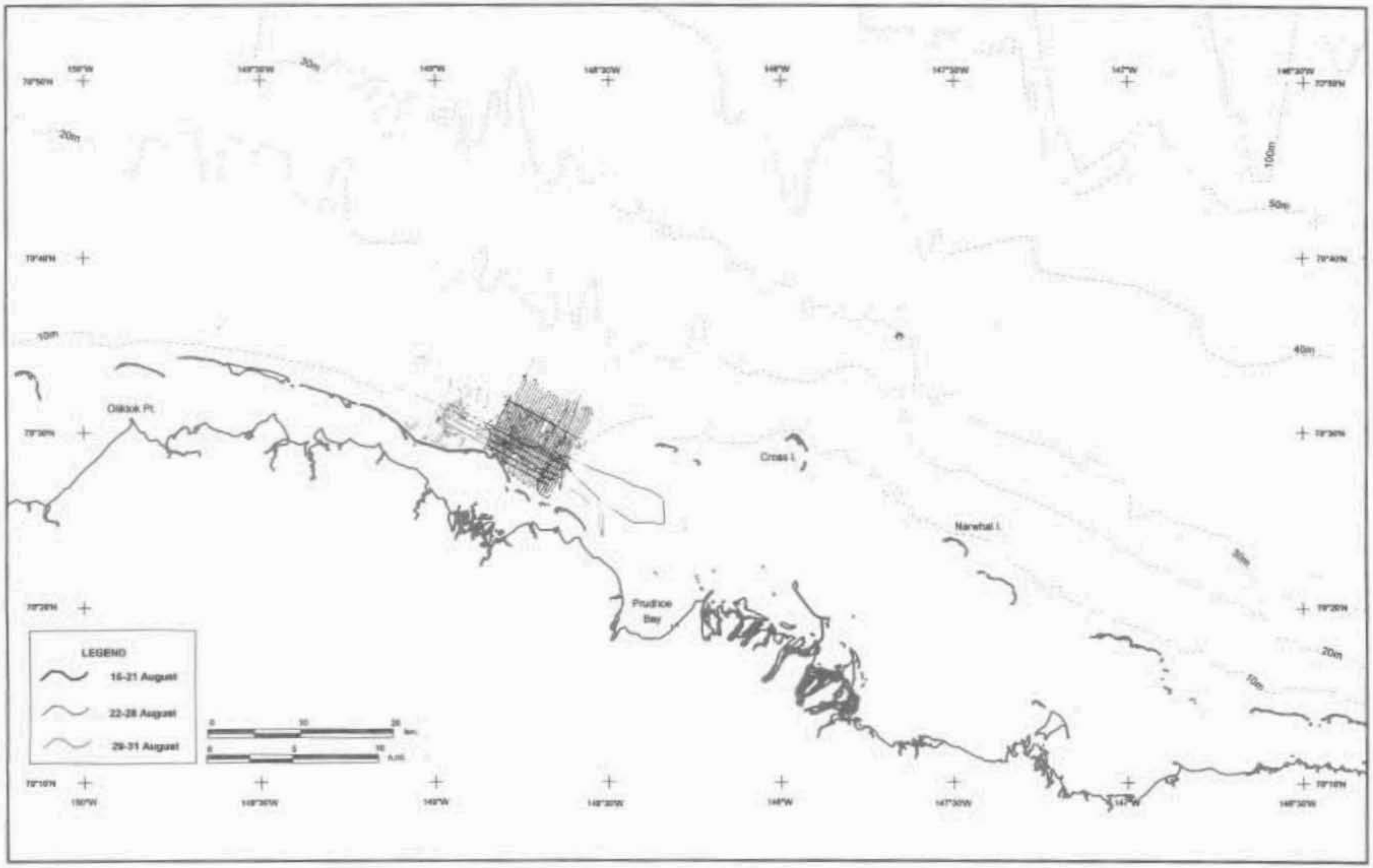

FIGURE 2.2. Movements of the seismic source vessel *Point Barrow* during the period 15-31 August 1996. Colors distinguish different weeks. See Figure 2.3 for movements of other vessels involved in the seismic operation during this period.

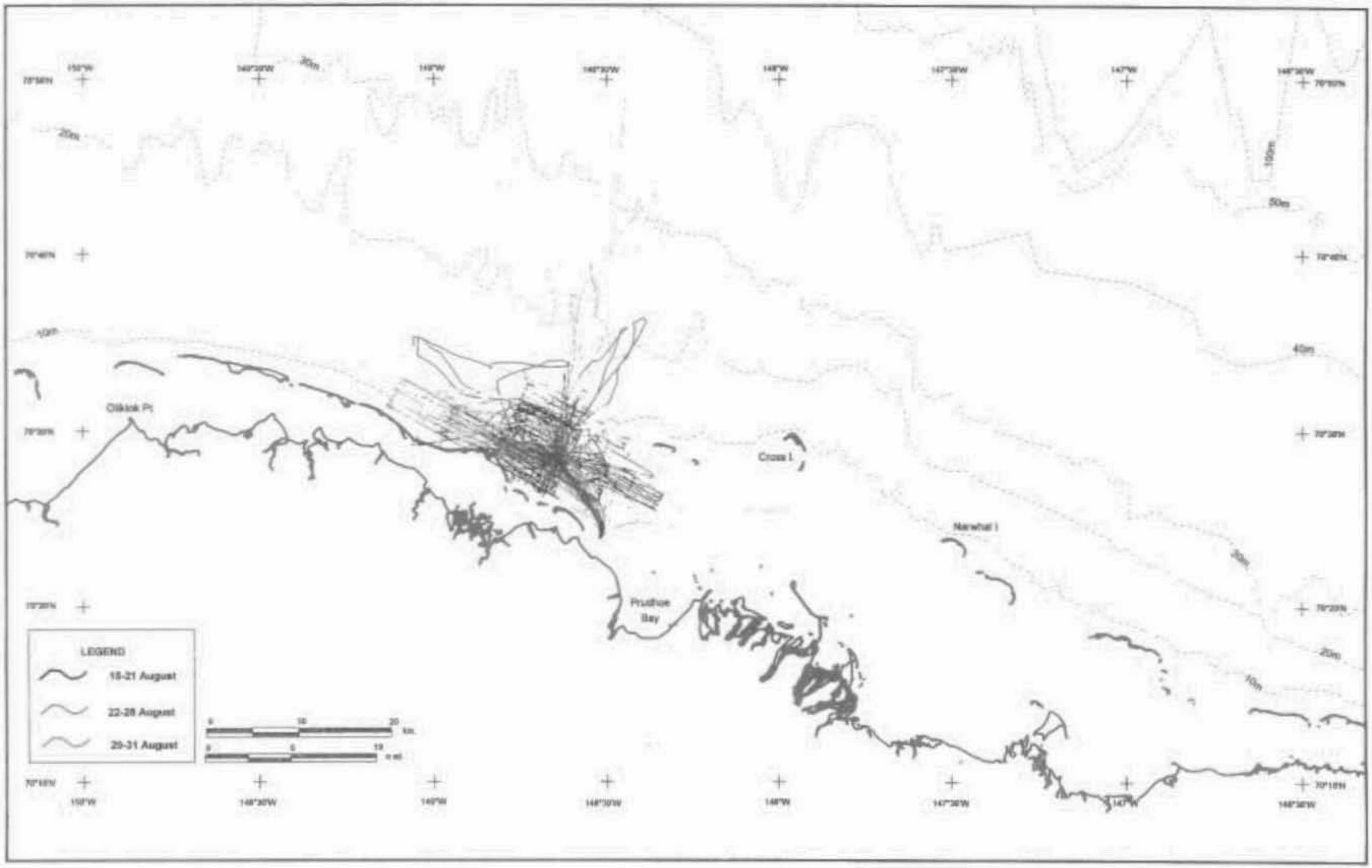

FIGURE 2.3. Movements of vessels involved in the Northstar OBC seismic operation, excluding the source vessel *Point Barrow*, during the period 15-31 August 1996. Colors distinguish different weeks. See Figure 2.2 for movements of the source vessel during this period.

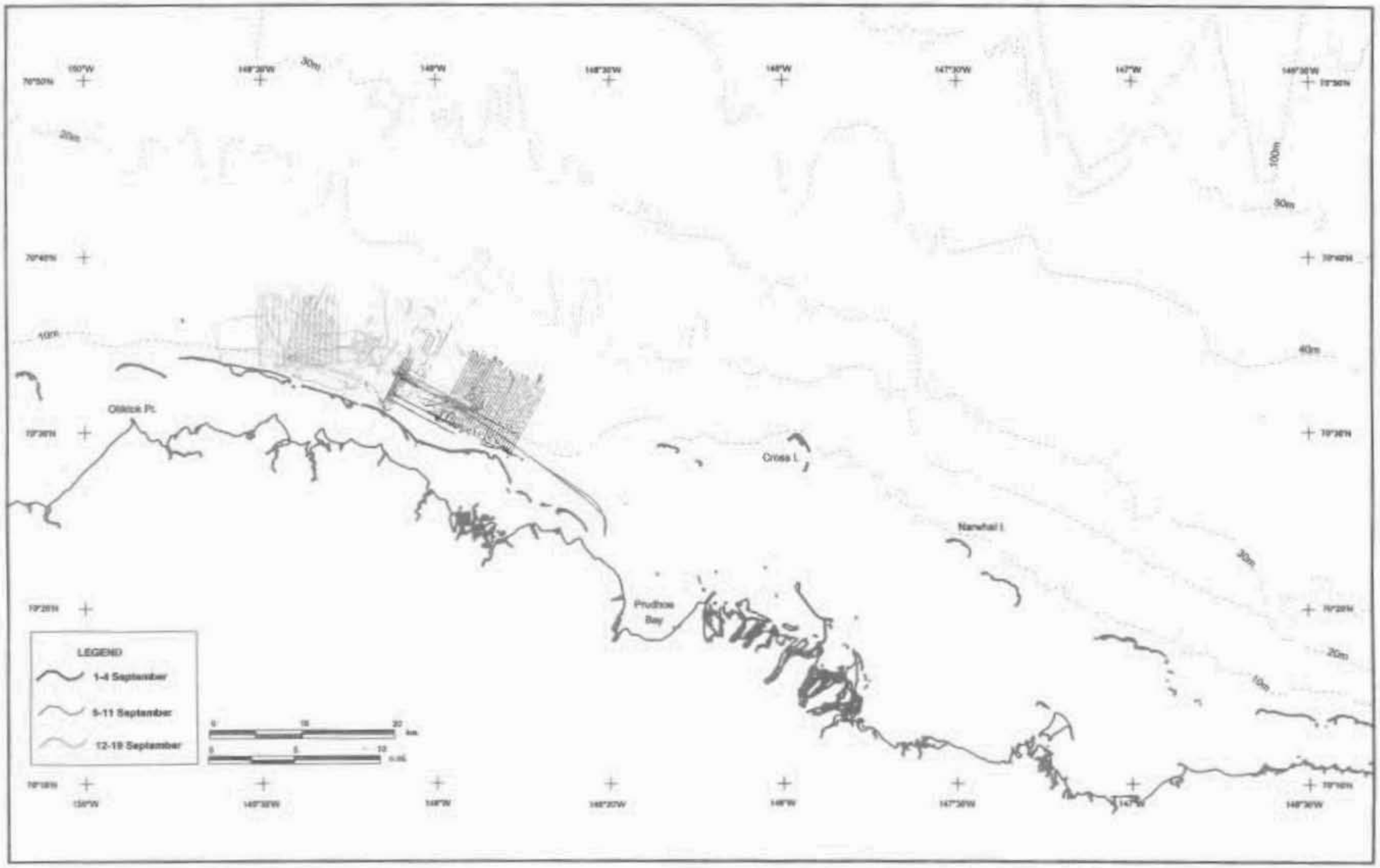

FIGURE 2.4. Movements of the seismic source vessel *Point Barrow* during the period 1-19 September 1996. Colors distinguish different weeks. See Figure 2.5 for movements of other vessels involved in the seismic operation during this period.

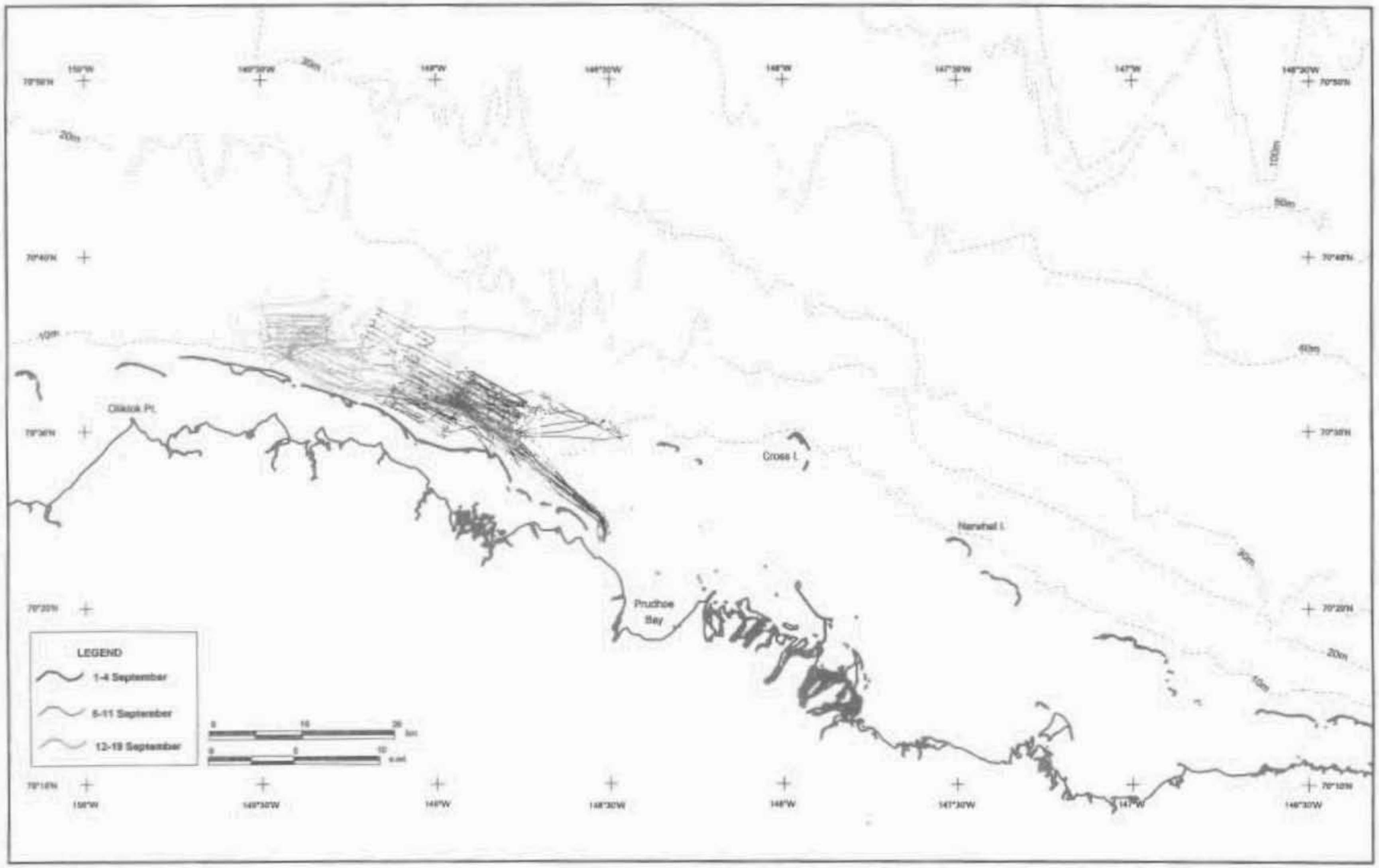

FIGURE 2.5. Movements of vessels involved in the Northstar OBC seismic operation, excluding the source vessel *Point Barrow*, during the period 1-19 September 1996. Colors distinguish different weeks. See Figure 2.4 for movements of the source vessel during this period.

There are some gaps in the automatically-logged files of vessel locations. For example, positions of the *La Brisa* were not logged on 27 August while it was deploying bottom-mounted acoustical recorders northeast of Cross Island. Positions of *Sag River* were not logged on 14-15 September while it was retrieving bottom recorders northeast of Cross Island (14th) and north of Northstar (15th). Before the *Sag River* traveled east of Cross Island on 14 September, the crew contacted the whaler coordination center. They confirmed that whaling was not in progress because of poor weather, and that the whalers had no objection to the *Sag River* traveling east of Cross Island on that date to retrieve the bottom recorders.

2.3 Marine Mammal Monitoring and Mitigation

Boat-Based Monitoring

The Incidental Harassment Authorization (IHA) issued by NMFS required that a minimum of two biologically-trained observers be present on the source vessel. Their duties included watching for and identifying marine mammals; recording their numbers, distances and reactions to the seismic operations; calling for mitigation measures when appropriate; and reporting the results. There was no requirement for suspension of seismic operations during times with poor visibility or at night, and in fact seismic work continued during such periods. Details of the boat-based monitoring effort are given in Chapter 4 on SEALS. (No whales were sighted from the source vessel.) This section includes only a brief introduction to the monitoring procedures, followed by a description of the mitigation measures that were implemented when marine mammals were seen close to the source vessel.

Two or three biologist observers plus one Inupiat observer/communicator were assigned to the source vessel at all times. Whenever shooting was underway, or when it was expected to begin within the next 30 minutes, the on-duty observer watched continuously for mammals. The observer scanned around the vessel using 7 x 50 Fujinon binoculars with a reticle to measure depression angle relative to the horizon (an indicator of distance). During July and much of August there was no total darkness. Thereafter the nights rapidly became longer. At night, the observers used both the 7 x 50 binoculars and a Bushnell/ITT Night Ranger 250 binocular night vision device (NVD). The IHA required nighttime monitoring only while the array was being powered up. However, in practice, monitoring personnel attempted to observe at all times, night or day, when the airguns were operating or were expected to start operating within the next 30 minutes. Notwithstanding the use of the NVD, the observers' abilities to detect marine mammals were severely reduced at night.

Aerial Monitoring

Aerial monitoring of a much larger region surrounding the area of seismic exploration was conducted on a daily basis, weather permitting, from 1 to 21 September. Aerial surveys after 18 September, when seismic work ended, were "post-seismic control" surveys. Poor weather prevented effective surveys on ⅓ of the days; surveys were done on 14 dates from 3 to 20 September. If any whales had been seen close to the source vessel during this work, this information would have been relayed by radio to the seismic source vessel and used in determining whether shutdown of the airguns was required in accordance with the 750 m criterion applicable for whales seen during September. However, the closest sightings of whales by the aircraft-based observers were much more than 750 m from the source vessel. The aerial monitoring procedures and results are described in Chapter 5 on WHALES.

Mitigation Measures

Ramp-up.—The IHA called for the airguns to be "ramped-up slowly over a period of several minutes" any time after the guns had been shut down "by firing the smallest gun first and then adding additional guns in sequence until the full array is firing".

Because all guns were the same size (120 in^3), the actual procedure applied during this project was to begin with one gun and to add additional guns in sequence over a period of 3-4 minutes. The specific ramp up sequence varied during the season. Sometimes one additional gun began firing every 20 seconds until all guns were firing. At other times, one gun was fired for the first minute, 2 guns for the second minute, 4 guns for the third minute, 8 guns for the fourth minute, and then all guns (normally 11 guns). The latter procedure resulted in close to a 6 dB increase in source level and (for distances within 500 m) in received level for every doubling of the number of airguns.[2] There were occasional variances from these nominal ramp-up sequences, but at all times efforts were made to ramp-up gradually rather than to suddenly begin firing with the full array.

The guns fired intermittently during normal operations—typically about once every 15-18 seconds, with the exact time interval depending on vessel speed. Thus, it was necessary to define how long a gap between shots could occur without it being necessary to ramp up before again firing the full array. Initially it was decided that ramp up would be required if there had been an interval of 1 minute or longer when no gun had fired. Late in the season, ice sometimes forced the vessel to slow down to the extent that it took more than 1 minute for the vessel to travel the 44 m between shotpoints. It was decided on 16 September that, under those conditions, ramp up would be required if there had been an interval of 2 min or longer since the previous shot.

Line Changes.—Procedures during line changes varied. A common practice was to continue firing some of the airguns during line changes to avoid the need to go through a full ramp-up sequence at the start of each line. The specific number of guns firing during line changes varied, but the intention was to keep at least 4 guns firing.

Shutdown Criteria.—The IHA required that the permittee "Power down the array whenever any seal enters, or is about to enter, the 500-ft (150 m) safety zone around the

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[2] At frequencies below 100 Hz, the individual airgun sounds added coherently (6 dB per two-fold change), and the array was essentially omnidirectional in azimuth. The airguns emitted significant sound energy at 150 Hz as well. The array was only slightly directional at 150 Hz, and the addition of components from the different airguns was only slightly incoherent at that frequency (see Chapter 3, PHYSICAL ACOUSTICS MEASUREMENTS, §3.3).

seismic source or whenever a whale enters, or is about to enter, the 2,130 ft (650 m) safety zone established around the source for these species."

The 150 m and 650 m radii for seals and whales, respectively, were based on an assumption that seismic pulses at received average pulse levels below 190 or 180 dB re 1 μPa (respectively) are unlikely to affect the hearing abilities of seals and whales, but that higher received levels might have some such effects. It is not known whether exposure to pulses of low-frequency underwater noise from marine seismic exploration can cause hearing damage in marine mammals (Richardson et al. 1995:372*ff*). However, there has been considerable speculation about this, based mainly on what is known about hearing damage to humans and other terrestrial mammals exposed to impulsive low-frequency airborne sounds (e.g. artillery noise). The 180 dB criterion for baleen whales was established by NMFS (1995) based on those considerations. NMFS concluded that there would be no hearing damage to baleen whales exposed to received levels of seismic pulses as high as 180 dB re 1 μPa. Because odontocetes like belugas are known to be less sensitive to low-frequency sounds than are baleen whales, NMFS (1995) concluded that the hearing apparatus of odontocetes would not be harmed by seismic pulses with received levels as high as 190 dB re 1 μPa. However, for this project BPXA proposed to apply the stricter 180 dB criterion to belugas as well as bowhead whales. Likewise, NMFS (1995) concluded that the hearing systems of pinnipeds would be less susceptible than those of baleen whales to seismic pulses. BPXA proposed and NMFS adopted a safety criterion of 190 dB re 1 μPa for seals.

Calculations done before the field season indicated that the average pulse levels would diminish below 190 dB at a distance less than 150 m and below 180 dB at about 650 m. These calculations were based on the expected characteristics of the seismic array and on previously-existing data on underwater sound propagation in the Sandpiper Island area, near Northstar (Miles et al. 1987:301).

The IHA also required that the permittee "Conduct, and provide a report on, an acoustic transmission loss test of the seismic source, within the Northstar Unit, prior to September 1, 1996. Based upon the results of this test, the safety zone described [above] may be modified accordingly." These measurements were done as part of the work described in Chapter 3 on PHYSICAL ACOUSTICS MEASUREMENTS. Based on this work, it was concluded that the received average pulse level could be as high as 190 and 180 dB re 1 μPa at distances as great as 250 m and 750 m, respectively. Therefore, on 30 August 1996, the safety radii for seals and whales were increased to 250 m and 750 m, respectively, for times when more than one airgun was in use. A modification of the IHA, dated 6 September 1996, formalized this change. The safety radii remained 150 m and 650 m when a single gun was being fired. Subsequent analyses of the sounds from a single airgun showed that the received sound levels diminished below 190 dB and 180 dB re 1 μPa at distances considerably less than 150 and 650 m, respectively (see Chapter 3).

It should be noted that the intention of the shutdown criteria was to minimize any possibility of hearing damage to marine mammals. Hearing damage, if it occurred, might be considered to be "Level A Harassment" (injury) under the provisions of the Marine Mammal

Protection Act. It is recognized that, at least among bowhead whales, disturbance reactions or "Level B Harassment" can occur at received sound levels lower than the shutdown criteria (see p. 1-1 *in* Chapter 1, INTRODUCTION). Thus, disturbance can occur at distances exceeding the shutdown radii. Disturbance to small numbers of marine mammals was authorized under the provisions of the IHA issued to BPXA for this seismic project, provided that it

- has a negligible impact on the species or stock(s) of marine mammals, and
- does not have an unmitigable adverse impact on their availability for subsistence.

Numbers of marine mammals that may have been disturbed by the seismic program, and the nature of this disturbance, are discussed in Chapter 4, SEALS, and Chapter 5, WHALES.

Shutdown Implementation.—No whales were seen from the source vessel, so only the seal criterion was relevant. Whenever the marine mammal monitor(s) or other personnel in the wheelhouse sighted a seal within the 150 m or 250 m shutdown radius, the navigator was notified immediately and the airguns were shut off. In the event that the navigator was not immediately available, the marine mammal observer activated a switch on the bridge to shut off the array. The airguns normally were shut off within 3 to 5 seconds after a seal was sighted inside the safety zone. Given the normal shot interval of about 15-18 s, there typically was either no shot or no more than one shot between the time the seal was seen and the time when the shutdown took effect. In total, there were 135 shutdowns for seals during the 24 July through 18 September 1996 period.

The procedure after shutdown varied. Sometimes the source vessel turned away from the seal and initiated a circle of about 300-400 m diameter. About half way around the circle, a ramp-up of the airguns was begun. This timing was selected so that, with a normal ramp-up schedule and with no further seal sightings, the full array would be shooting by the time the vessel returned to the point on the source line where the shutdown had occurred. At that point, the vessel resumed the original course along the source-line.

On other occasions, the vessel continued along the source-line after shutting down the airguns, and resumed firing when more than 150 m or 250 m (depending on date) beyond the seal's location. This necessitated not firing the airguns at several of the pre-planned shot-points, which were at 44 m intervals. "Missed" points were sometimes shot at a later time.

When another seal sighting occurred within the safety zone during a shutdown, the shutdown continued until no seals were known to be within the safety zone.

Field Reports

Throughout the seismic program, the boat-based marine mammal monitoring team prepared weekly reports summarizing the numbers of seals sighted with and without seismic shooting, the distances of these seals from the airguns, and the apparent reactions (if any) to the boat and/or airguns. These reports were faxed to the National Marine Fisheries Service, Western Alaska Field Office, with follow-up telephone contact to discuss any questions or concerns.

During periods when physical acoustic measurements were being taken (primarily during the latter half of August), weekly reports summarizing the acoustic work accomplished were also faxed to the NMFS Western Alaska Field Office, Anchorage. In addition, on 30 August 1996 the required report on the sound propagation tests was provided to that office and to the NMFS Office of Protected Resources, Silver Spring, MD.

During the 1-21 September period while daily aerial surveys were being conducted, daily reports were faxed to the NMFS Western Alaska Field Office. These summarized the survey coverage and bowhead whale sightings each day.

2.4 Literature Cited

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NMFS. 1995. Small takes of marine mammals incidental to specified activities; offshore seismic activities in southern California. **Fed. Regist.** 60(200, 17 Oct.):53753-53760.

Richardson, W.J., C.R. Greene Jr., C.I. Malme, D.H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego, CA. 576 p.

3. PHYSICAL ACOUSTICS MEASUREMENTS[1]

3.1 Introduction

The 1996 Northstar seismic program was conducted under the provisions of an Incidental Harassment Authorization (IHA) issued by the National Marine Fisheries Service (NMFS) to BP Exploration (Alaska) Inc. (BPXA). The IHA required that a marine mammal and acoustical monitoring program be conducted.

An array of airguns is the most common energy source used during modern open-water seismic exploration programs. An airgun array emits strong, low-frequency sound pulses into the water at intervals of several seconds. Geophysical survey contractors design their airgun arrays to focus the sounds downward insofar as possible. Even so, strong pulses of low-frequency sound propagate horizontally through the water. Their received levels tend to diminish with increasing distance. However, even in the horizontal plane, the source levels of the pulses are strong enough that the pulses are often detectable many tens of kilometers away (Greene and Richardson 1988; Richardson et al. 1995:136*ff*).

The size, number and positioning of the airguns comprising an array are customized for different applications. For example, arrays for shallow water surveys generally will not be as large as arrays for deep water surveys. Larger arrays generally emit significantly more sound than a middle- or small-sized array. In addition, sounds from an airgun array in deep water generally will transmit farther at higher levels than the sounds from a similar array in shallow water. Thus, a shallow water survey may create less sound at a given distance than a deep water survey for two reasons: a smaller source and poorer sound transmission.

Airgun sound pulses are undoubtedly audible to at least some marine mammals, including baleen whales, at long distances from the airgun array (Richardson and Würsig in press). Bowhead and other baleen whales often are disturbed when exposed to strong seismic sounds. They sometimes may react at least subtly to weaker seismic sounds as well (see §1.1). However, they probably are not always disturbed when they detect weak sounds from a distant airgun array. The circumstances when they are or are not disturbed are not adequately documented. As part of any attempt to monitor or study the reactions of marine mammals to seismic exploration, it is important to understand the characteristics and levels of the seismic sounds in the situations where the mammals were studied.

Tasks and Objectives

The final Technical Plan for this monitoring program included three acoustical measurement tasks:

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[1] By Charles R. Greene Jr., Greeneridge Sciences Inc., assisted by John S. Hanna and Robert W. Blaylock.

- "conduct a vessel-based acoustics program for ~10 days in late August 1996 to obtain systematic measurements of seismic sounds, propagation loss, and ambient noise;"
- "drop sonobuoys during the aerial survey program beginning 1 September to collect data on (a) ambient noise and (b) seismic exploration noise. Sonobuoys would provide noise data at more places and times, and under more environmental conditions, than possible from the vessel, including ambient and seismic data from bowhead locations;"
- "deploy bottom-mounted acoustic recording devices at several locations east of and offshore of the Northstar region to obtain near-continuous records of underwater noise and whale calls in those areas from 1 September to the end of the seismic program (or until ice precludes data retrieval)".

The resulting acoustical measurement program documented the major types of underwater sounds associated with the seismic program. The main sources included the airgun array, a single airgun, various project vessels, and the aircraft used for aerial surveys of whales. In addition, sound propagation conditions within the Northstar area and from there northward toward the main whale migration corridor were studied. During the bowhead whale migration period, continuous acoustical monitoring was conducted to listen for whale calls and seismic pulses at two locations, one offshore from Northstar and one much farther to the east. Ambient noise was also recorded and analyzed at many locations in and near the Northstar area.

As called for by the three tasks listed above, three general approaches were used to achieve the acoustic measurement objectives: (1) one or two hydrophones were deployed from a boat, the *La Brisa*, while at anchor in the Northstar survey area or drifting several kilometers offshore; (2) sonobuoys were deployed from the aircraft that was conducting aerial surveys of marine mammals during the 1-21 September period, as described in Chapter 5, WHALES; and (3) seven autonomous bottom recorders were installed to collect acoustic data at various distances offshore in areas north and east of Northstar during the first three weeks of September. Also, four bottom recorders were installed north of Northstar on 24 August for three days in a test deployment. Figure 3.1 shows the areas where seismic exploration occurred during the period of acoustical measurements, and the locations where the bottom recorders were installed. The two long-term bottom recorders whose data are available for use in this report were located at two sites: (1) 15 km (8 n.mi., 9 st.mi.) offshore of the northern edge of the seismic exploration area; and (2) 20 km (11 n.mi., 12 st.mi.) ENE of Cross Island and 14 km (7.5 n.mi., 8.7 st.mi.) north of Narwhal Island. The latter location is 45 km (24 n.mi., 28 st.mi.) to the ESE of the other recorder.

Subsequent to the August-September field season, a major acoustical analysis effort was conducted to extract the needed data from the field recordings and other records of field activities.

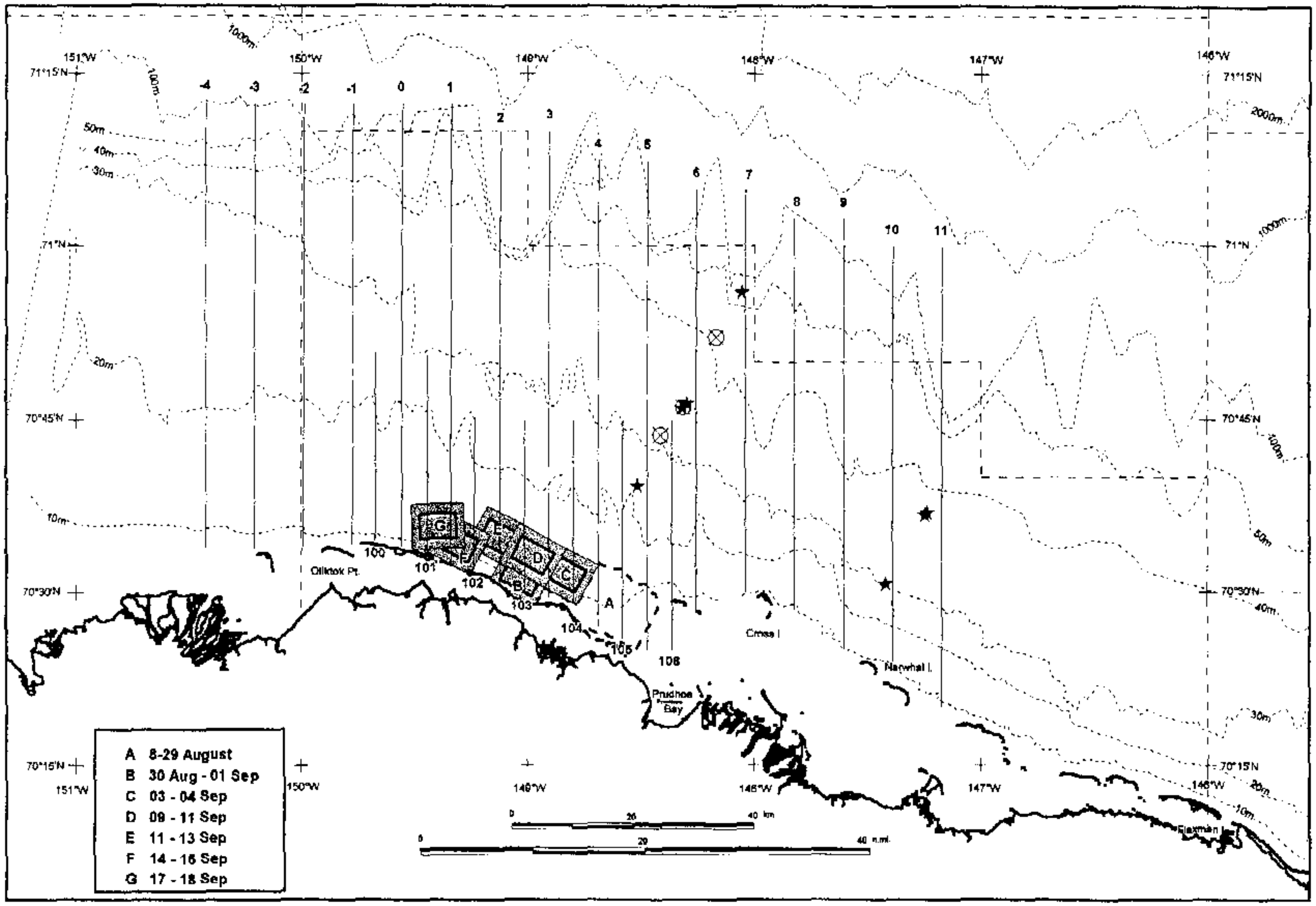


FIGURE 3.1. Central Alaskan Beaufort Sea showing the Northstar area where seismic operations occurred from 8 August through 18 September 1996, and the locations of bottom recorders (⊗ for the 3-day test in late August; stars for the long-term deployment commencing 31 Aug.) B to F are the six "patches" where seismic surveys were done during the long-term deployment, starting at 00:00 ADT on 31 August. The southernmost recorders off Narwhal Island and Northstar were retrieved on 14 and 15 September, respectively. The north-south lines are aerial survey transects (see Chapter 5).

Concepts and Terminology

Acoustic concepts and terminology are generally confusing to non-acousticians, and often to acousticians as well. An attempt to summarize the concepts and terms relevant in assessing noise effects on marine mammals was given in Chapter 2 (and the associated Glossary) of Richardson et al. (1995). A few remarks about terms used in this report are included here.

The word "level" is used to denote a sound measurement in decibels. A one decibel (dB) change in sound level is considered to be the smallest change in sound level perceptible to a human listener. A change of +10 dB or -10 dB is perceived by a human listener to be, respectively, about a doubling or a halving of the sound level (i.e. a two-fold change). However, in physical units, a 10 dB change in sound level actually corresponds to a ten-fold change in sound power (commonly measured in watts) and a three-fold change in sound pressure (commonly measured in micropascals).

A doubling of the sound pressure corresponds to a 6 dB increase in sound pressure level. A doubling of the sound power corresponds to a 3 dB increase in sound pressure level. The decibel value of a sound level is the same whether one uses a power reference or a pressure reference; the equation to compute the sound level in decibels allows for the fact that sound power is proportional to the square of the sound pressure.

Unrelated sound sources add incoherently, meaning that the sound waveforms are not correlated and that the sound powers in each add to result in the sound power of the sum. Related sound sources, i.e. sound sources with the same waveforms, may add coherently, meaning that the sound pressures add to result in the sound pressure of the sum. For coherent waveforms, the sum of two equal sources is twice the sound pressure and four times the sound power of either source (i.e., a 6-dB higher sound level). Closely spaced airguns firing at the same time have related waveforms that add coherently.

In calculating average sound levels over specified lengths of time, the common practice is to square the pressures and average them, obtaining a mean square pressure, and then compute 10*log(mean square) to obtain the sound pressure level. An alternative procedure is to compute the square root of the mean square to obtain the "root-mean-square" or rms sound pressure, and then compute 20*log(rms) to obtain the sound pressure level. The results are the same, and it is convenient to refer to the value derived by either procedure as an rms pressure level.

"Peak" and "rms" pulse levels for received airgun signals are described and compared in sections 3.2 and 3.3, below. In general, the peak level is the instantaneous maximum or minimum value whereas the rms level is an average over the pulse duration. Another term used to emphasize this distinction is the "crest factor" of a waveform, which is the ratio of the peak level to the rms level. The crest factor of a sinusoidal waveform is 1.4, or 3 dB.

Regarding distance measures other than the MKS standard kilometer, the usual practice is to use statute miles (st.mi.) on land and nautical miles (n.mi.) at sea. One nautical mile is equal to 1.15 st.mi. and to 1.85 km.

3.2 Methods

Boat-Based Measurements

Two hydrophones were deployed from the stern of *La Brisa*. An International Transducer Corporation (ITC) model 6050C hydrophone with built-in low-noise preamplifier was suspended from a sparbuoy drifting near the vessel. An ITC 1103 hydrophone without built-in preamplifier was suspended directly from the stern. Both hydrophones were deployed at depth 9 m, except that, where the water was shallower, the hydrophones were raised to be about one meter above the bottom. The 1103 hydrophone was capable of receiving very strong signals, up to 220 dB re 1 µPa peak pressure, without distortion. This hydrophone was useful at the shortest distances from the airguns. The 6050C hydrophone was useful at long distances from the airguns and for measuring the ambient noise. It would distort when the received signals exceeded 179 dB re 1 µPa. In those cases, data from the ITC 1103 were used.

The 1103 hydrophone cable was attached to a preamplifier in the boat's cabin. The preamplifier gain could be selected in 10 dB steps from 0 to 60 dB. The 6050C hydrophone cable was connected to a postamplifier in the boat's cabin. The postamplifier gain could be selected in 10 dB steps from 0 to 60 dB. The two amplifier outputs were connected to the inputs of a TEAC model RD-101T digital audio tape (DAT) recorder. This recorder permits recording with a dynamic range of about 80 dB, meaning that there is a large range of amplitudes between self-noise and distortion. In addition, the speed accuracy and stability of the recording permits reproducing signal frequencies very accurately and without the flutter and wow associated with non-digital recorders. A memo channel permitted recording annotation by voice without disrupting the data recording.

The boat-based measurement system was used in two ways. In one, *La Brisa* anchored in the survey patch at a point selected because the operating airguns would be passing within about 100 m. This approach provided data on the received levels of airgun pulses at varying distances during the approach and subsequent departure of the source vessel. Both hydrophone signals were always recorded during such runs because the 6050C preamplifier overloaded at the closest distances and the relatively insensitive 1103 hydrophone was required. In the other application, *La Brisa* motored to a distant position either NNE or WNW of the survey patch and drifted while recording the airgun sounds. The 1103 hydrophone was not always used at these long distances, where received levels were lower, because the 6050C provided high-quality signals.

In addition, sounds from four vessels involved in the Ocean Bottom Cable seismic operation were also recorded. All vessels involved in the operation are listed and described in §2.2, "Equipment and Operations".

La Brisa had a 3 kw inverter for converting battery power to 120 V ac power during quiet recording operations. This inverter powered heaters, ventilators, pumps and electronics like the fathometer, radio and GPS computers on the vessel, some of which created hum in the acoustic signals. Generally we were able to find and turn off such troublesome auxiliary equipment, but there were instances when low-level residual hum appeared in our data at 60 Hz or in the ⅓-octave band centered at 63 Hz.

Distances between recording vessel *La Brisa* and the various vessels whose sounds were measured were determined by radar and by Differential GPS (DGPS). Positions of all major vessels involved in the seismic operation were determined continuously by DGPS (accuracy within ~1 m), and were logged into computer files every 5 min. Also, the position and heading of the airgun array were determined by DGPS and logged for every airgun pulse during production surveys. The water depth at the airgun array location, as determined by fathometer, was also logged for every such pulse.

Sonobuoy Measurements

Sonobuoys were procured from the Sparton Corporation for use from the survey aircraft. They were model AN/SSQ-57A omnidirectional, wide-range sonobuoys calibrated (±2 dB) over the frequency range 10-20,000 Hz. These buoys employ a wideband FM radio transmitter to achieve low instrument background noise. However, their radio power is only one watt and sonobuoy signals received aboard the aircraft became contaminated by radio static as the aircraft departed the vicinity of the buoy, especially at low altitudes. On the aircraft, a four-channel sonobuoy receiver was connected to an antenna through a low-noise RF preamplifier to minimize noise induced by the antenna cable. The signals were recorded on a TEAC model RD-135T DAT recorder effective (in four channel mode) at frequencies up to 10 kHz. The operator monitored the audio quality with a headset and made voice announcements on the recorder's memo channel.

All sonobuoys obtained for the survey were modified during manufacture to deploy the hydrophone to a depth of 10 m instead of the standard 18 m hydrophone depth. This change was made to permit deployment of some sonobuoys in the shallow waters around Northstar. In addition, some of the sonobuoys had sensitivities that were reduced by 20, 30 or 40 dB compared to standard AN/SSQ-57A sonobuoys. This was to permit recording the expected higher levels of airgun sounds without distortion. Standard sonobuoys are designed to detect and monitor low-level sounds. The standard AN/SSQ-57A can begin to distort on sounds with received levels on the order of 127 dB re 1 μPa, depending on frequency. Sonobuoys desensitized by 20, 30 or 40 dB would not distort unless the received signals exceeded about 147, 157 or 167 dB re 1 μPa, respectively.

At least one sonobuoy was dropped offshore of the Northstar area during most aerial surveys in order to monitor ambient noise and seismic sounds. On days when seismic exploration was underway and bowhead whales were seen, sonobuoys usually were dropped near one or more of the bowheads. To avoid overloading the sonobuoys, reduced-sensitivity buoys were used when the seismic vessel was operating nearby.

Bottom Recorder Measurements

The third approach to acoustic data collection involved the use of autonomous devices installed on the ocean bottom remotely from the survey area. These were designed to provide continuous acoustic data over extended periods, including information about seismic pulses, ambient noise, and bowhead whale calls. The objective was to obtain acoustical data from three pairs of locations east of and offshore of Northstar—one pair of locations near the southern edge of the bowhead migration corridor, one pair near its center, and one pair farther offshore. In practice, recording units were deployed at five of the six planned locations (Fig. 3.1). To date, data have been recovered successfully from the southernmost two locations, and it is hoped that the remaining recorders can be recovered during the 1997 open water season.

Batteries and electronics were housed in a 6" PVC pipe, 52" long, with machined aluminum end caps and double O-ring seals. The inside ends of the PVC pipe were machined to match the O-rings on the end caps. The sole penetration was for a hydrophone cable connector. The hydrophone, buoyed up 2 m above the bottom, was an ITC model 8212, a cylindrical unit containing a low-noise preamplifier. The frequency response was flat below 3.5 kHz and was within ±3 dB of being flat to 30 kHz. An amplifier/filter in the bottom recorder unit low-pass filtered the hydrophone signal into two bands, 5-500 Hz and 5-1000 Hz. The remaining electronics, provided by Dr. David Jacobs of Scripps Institute of Oceanography, included an Onset Tattletale 7 controller with a two-channel analog-to-digital converter and SCSI interface for a 4 GByte disk drive. The hydrophone signal was sampled continuously 1000 times per second (500 Hz passband) for 13 minutes and 24 seconds, after which the sample rate doubled (1000 Hz passband) for one minute. Once every 14 min 24 s, the buffer memory was dumped to the disk, requiring disk operation for about 50 s. The disk capacity was 24.94 days, and the battery capacity, limited by the disk power requirements, exceeded 22 days.

This procedure provided a continuous record of sounds at frequencies up to 500 Hz. In addition, exactly 100 times per day (every 14.4 min), sounds at frequencies up to 1000 Hz were recorded for 1 minute. These wider band sounds were analyzed for ambient noise.

A test deployment of four bottom units offshore of Northstar on 24 August was largely successful. During deployment, the locations of the units and their 100-m tag line anchors were recorded with Differential GPS. The units were installed at water depths ranging from 25 to 44 m, based on *La Brisa's* fathometer. These depths occurred at locations expected to bracket the bowhead whale migration corridor, whose center is estimated to be at a depth of 35 m. The four units were programmed to begin sampling at 00:00 local time (ADT) on 25 August. On 28 August the four units were retrieved without difficulty by grappling at those locations for the tag line attached to each unit. The disk drive had not operated properly on one of the four units. However, about 80 hours of data were recorded on each of the three successful units.

Seven units were deployed on 27-28 August for longer-term acoustic monitoring. All units were programmed to begin operation at 00:00 ADT on 31 August. The units were deployed along two lines extending offshore from Northstar and offshore from Narwhal Island, east of Cross Island (Fig. 3.1).

- Three units were deployed on 27 August on an 030° True line starting 20 km ENE of Cross Island (14 km north of Narwhal Island). One unit was deployed at a location where water depth was 31 m, and two units were deployed ~350 m apart where water depth was 42 m (water depths based on *La Brisa*'s fathometer). Heavy seas prevented us from deploying a planned fourth unit farther offshore along that line.
- Four units were deployed on 28 August on a line oriented perpendicular to shore (030° True) seaward of Northstar at water depths 25 m, 36 m (2 units ~1 km apart) and 44 m.

Two units were deployed at the "middle" location along each line in order to increase the probability that data would be acquired from the center of the bowhead migration corridor both east of and offshore of Northstar.

The southernmost recording unit from each line was retrieved successfully on 14 and 15 September, despite the presence of significant ice cover. Heavier ice prevented retrieval of the five units at more northerly locations. Those units are at locations deep enough for there to be little chance of damage by ice scour during one winter. It is planned to retrieve as many of those units as possible during August 1997, and to analyze the 1996 data recorded by those units as part of BPXA's 1997 seismic monitoring program.

Signal Analysis

Seismic Survey Pulses.—For each airgun pulse recorded on *La Brisa*, the recorded signal was sampled at a rate of 8192 samples per second during a 60-s to 90-s block of time containing several pulses. This process effectively determined the instantaneous pressure 8192 times per second throughout that block of time. For each pulse studied, the time series of these instantaneous pressure measurements was analyzed.

Seismic pulses received via sonobuoys were similarly digitized. These digitized signals required special attention because sonobuoy sensitivity increases steeply with increasing frequency from 10 to about 3000 Hz (see Fig. 3.1B in Richardson et al. 1995). This shaped frequency response increases the buoy's dynamic range by de-emphasizing the low frequency sounds, which often are at higher levels, and enhancing the higher frequencies, which tend to be at lower levels. (Note the negative slope in ambient sea noise spectra such as those shown in Fig. 5.2 in Richardson et al. 1995.) The frequency shaping distorts the pulse shape depending on the frequency content in the pulse. To compensate for this sloped frequency response, the block of samples containing an airgun pulse was Fourier transformed, the transform magnitude was altered based on the frequency calibration of the individual sonobuoy to achieve an overall flat response, and the block was inverse Fourier transformed to obtain a corrected time series. This process was designed to yield the waveforms, peak pressures, energies, and rms pulse pressures that would have been measured if the sonobuoy frequency response had been flat.

Airgun pulses recorded on the bottom units were digitized at 1000 samples/s when they were recorded. Otherwise, their analysis was like that of the boat-based recorded pulses.

Clipping: Overloading is recording distortion that occurs when signal amplitude exceeds the range of the amplifier or recorder. Cases of overloading were detected by looking for clipping. A clipped signal includes many samples with apparent amplitudes at or close to the maximum amplitude. The computer program doing the analysis counted the samples within one percent of the highest amplitude in the segment being analyzed. Results were considered to be clipped, and were discarded, when more than 5-10 samples had amplitudes within 1% of the maximum. This process was most important with the sonobuoys, when there was no second, less-sensitive channel against which to compare results (as there was on the boat).

Generally, overload distortion occurred on the channel with the ITC 6050C hydrophone when it was within 1-2 km of the operating full array, or about 100-200 m of a single airgun. As the range to the airguns decreased, the pulse amplitudes from that channel appeared to stay at the same level while the pulse amplitudes from the ITC 1103 hydrophone channel continued to increase. In those cases it was clear that the 6050C channel had overloaded.

Quantification of Pulse Levels: No single standard method has been used in the literature to report airgun signal levels with respect to their effects on marine mammals. We use and compare three measures during this study. These measures are illustrated in Figure 3.2.

1. *Peak pressure* (in micropascals), either positive or negative, of each pulse. This is the instantaneous maximum or minimum pressure observed during the pulse, in μPa, and neglects any consideration of pulse duration.

2. *Energy in the pulse*, in μPa^2-s. To compute the energy, one must first determine start and end times for the pulse, which is difficult because of noise present at the beginning of the pulse and reverberation at the end. The approach developed in this study was as follows. The analysis program computes the standard deviation of the acoustic pressures in the total sample (nominal length 60 s) and then identifies those samples whose pressures are at least 6.25 times the standard deviation. Most of these samples represent airgun pulses. The program identifies sequences of such pulses, and extends these sequences by 1 s in advance of the first high-valued sample and by 2 s following the last high-valued sample in the sequence. These extended segments, typically slightly more than 3 s in duration, are presented to the operator as a graph of pressure vs. time. If he accepts the program's identification of the sequence as an airgun pulse, the program proceeds; otherwise, the operator manually selects the airgun pulses. Samples outside these extended segments are taken to be noise and are used to compute the level of the ambient noise. Again, the operator can override the program's selection of noise periods.

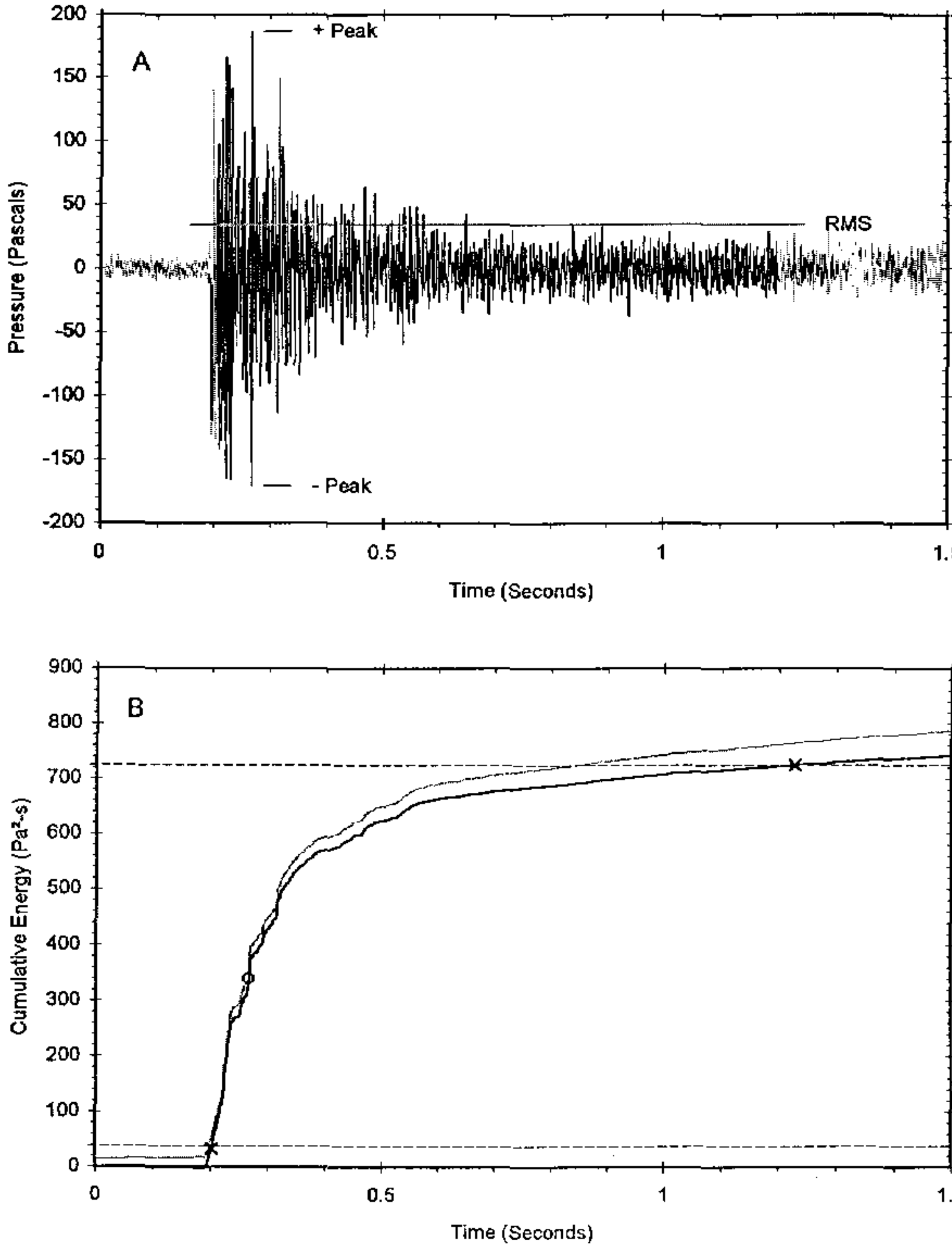


FIGURE 3.2. Airgun sound pulse measures. *(A)* shows waveform of an airgun pulse. *(B)* shows the cumulative squares of the unadjusted pressure samples (faint line) and the cumulative squares of the pressure samples excluding ambient noise (thick line). The point of maximum instantaneous pressure magnitude is identified by an O, and the 5th and 95th percentiles of the energy summation are marked (horizontal dashed lines).

Within an extended segment containing an airgun pulse, the computer program sums the squares of the time series of instantaneous pressure measurements, subtracts the average of the squared noise samples, and multiplies by the sample period Δt:

$$\text{Sum} = \Delta t^{*}\Sigma(p^2 - n^2_{avg})$$

The program develops a table of values giving the cumulative energy from the start to the end of the sequence of samples being analyzed. This cumulation increases slowly (because of the background noise) until the pulse starts, then increases rapidly through the pulse duration, and finally (after the end of the pulse) increases slowly again (Fig. 3.2B). From this cumulative table, the 5^{th} and 95^{th} percentile values are determined; these are taken as the effective starting and stopping times of the pulse, thereby determining the *pulse duration*. The pulse energy is taken as the accumulated value, exclusive of the estimated ambient noise contribution, at the 95^{th} percentile time less the accumulated value at the 5^{th} percentile time.

3. *Rms pressure* during the pulse. This is the square root of the energy divided by the duration. When presented as a level, in dB re 1 µPa, the rms pressure level is equivalent to the mean square pressure level of the pulse. This third measure, which might be called the average pulse pressure, has been used by BBN in its measurements of airgun signals (C.I. Malme, pers. comm.). National Marine Fisheries Service criteria concerning apparent reaction thresholds of whales to seismic signals (e.g., NMFS 1995) are based largely on those BBN measurements. Rms pressure levels are expressed in dB re 1 µPa.

Except where otherwise noted, pulse levels reported in this chapter are rms pressure levels. It is natural to want to compare the relationships of rms pulse pressure levels with the other two measures, but one must be careful because the unit of energy differs from the unit for pressure. Although all three may be expressed as levels in decibels, the reference unit for the energy measure is different from the reference unit for the peak and rms pressures. As an illustration, Figure 3.3 shows all three measures for a series of received pulses.

Spectrum Analysis.—Standard spectrum analysis techniques were used to study ambient noise, boat and aircraft noise, and acoustic transmission loss. A series of samples was segmented into blocks of a varying number of samples depending on the application, with successive blocks overlapping by 50%. Each block was "windowed" by the Blackman-Harris minimum three-term window (Harris 1978) to minimize "leakage", and then transformed by fast Fourier transform to obtain the magnitude of the power in each frequency cell. The successive results of the block transforms were averaged, divided by the effective analysis bandwidth (including the windowing effects), and log transformed to obtain power spectral density levels in dB re 1 $\mu Pa^2/Hz$. These "raw" results were then adjusted to allow for the frequency-specific sensitivity curves of the hydrophones, amplifiers, sonobuoys, sonobuoy receivers, and tape recorders as appropriate for the particular measurement in question.

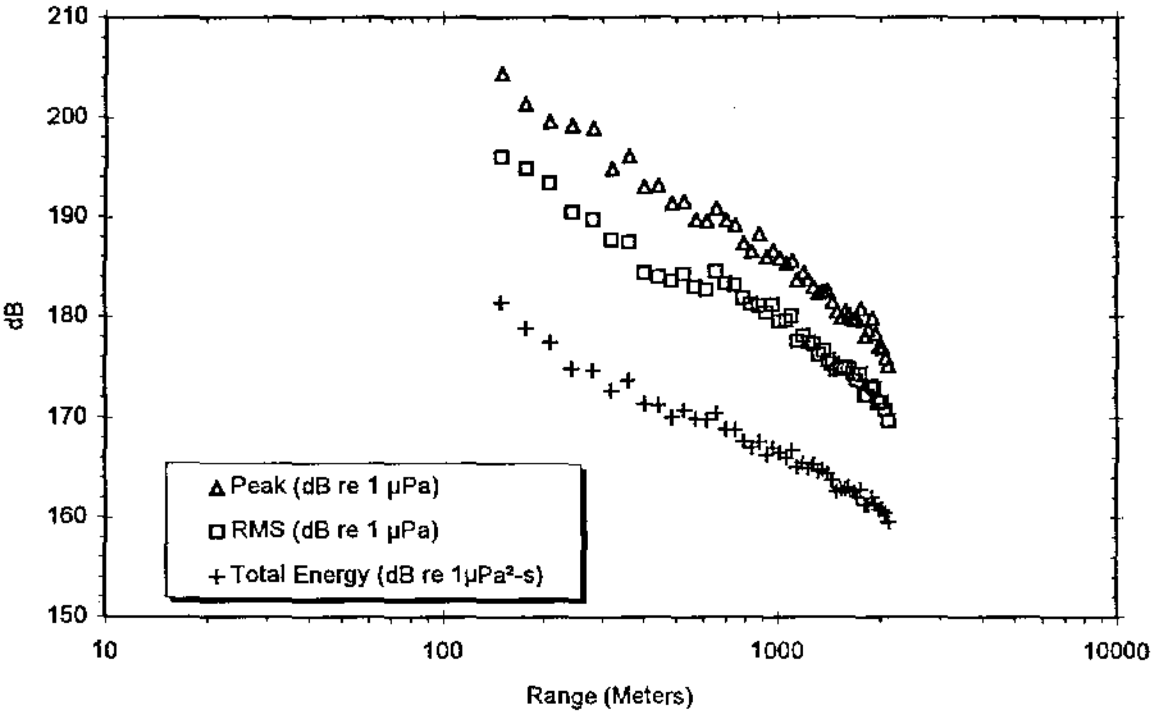


FIGURE 3.3. Examples of the range-dependence of peak pressure levels (in dB re 1 µPa), rms pressure pulse levels (also in dB re 1 µPa), and pulse energy levels (in dB re 1 μPa^2-s) from the 11-airgun array operating on 15 August 1996 in water 9-11.5 m deep, stern aspect.

3.3 Seismic Source Characteristics

An 11-airgun array was towed behind the tug *Point Barrow* as the source of sounds for the 3-D seismic survey at Northstar. The array configuration is shown in Figure 3.4. The nominal depth of the array was 3.5 m, with one airgun below the others by an additional 0.64 m. The array consisted of two strings, one on the left (port) side with five airguns and the other on the right (starboard) side with six airguns. Each airgun's capacity was 120 in^3 and all airguns were fired simultaneously.

An airgun "fires" when a solenoid actuates to cause a volume of high-pressure air to suddenly vent to the water outside, forcing the water back as a bubble forms around the airgun (Kramer et al. 1968). A sharp pressure pulse is created when the water moves.

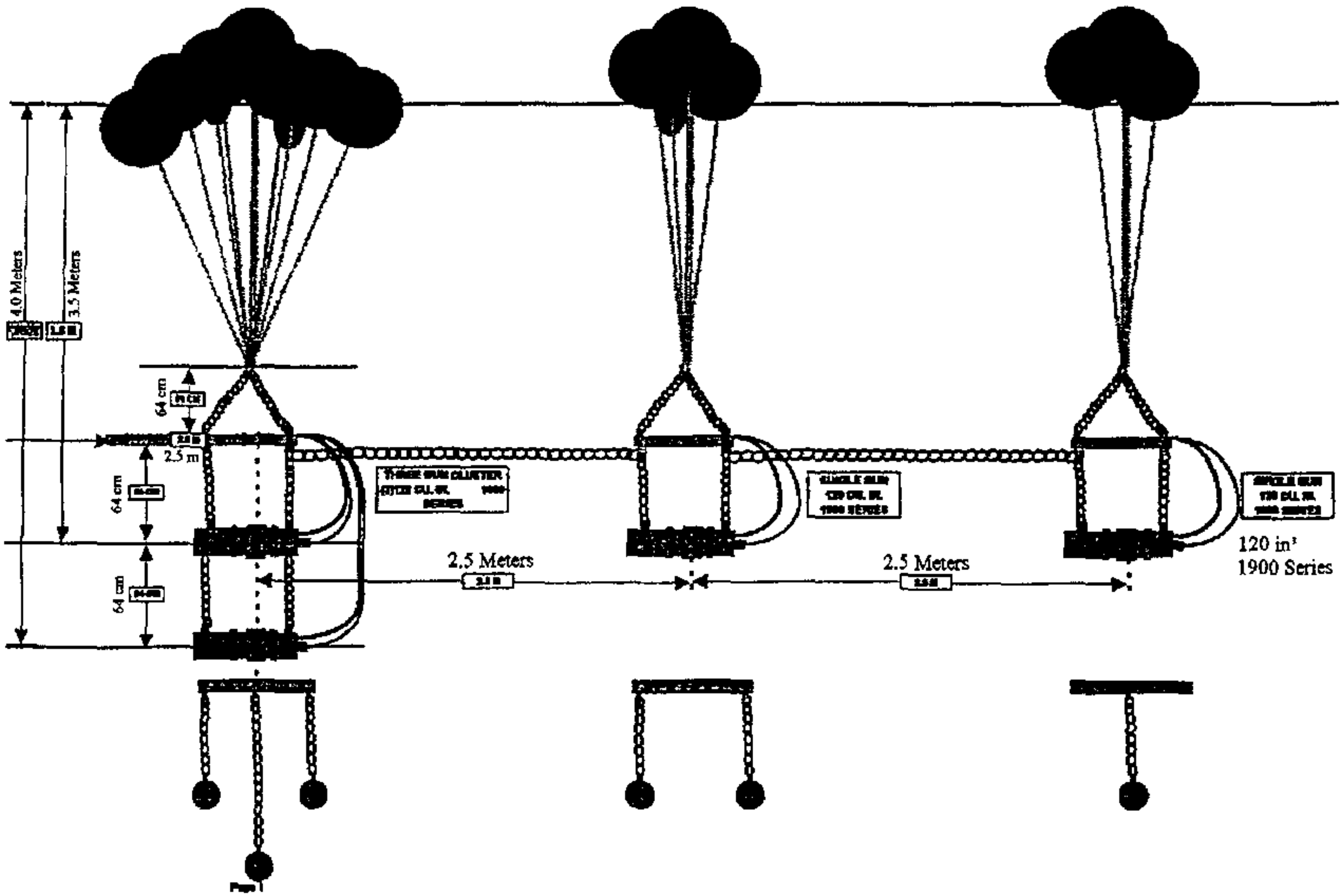


FIGURE 3.4. Airgun array configuration. This is an elevation view of the left (port) array with five airguns showing the three sets of surface floats holding up the airguns. The right (starboard) array parallels the left array, separated by 5 m, with two airguns at the center position where there is one airgun on the left array. Each gun has a 120 in^3 capacity; the 11 airguns total 1320 in^3. The centers of the forward airguns are 11.5 m behind the stern of the towing vessel, the *Point Barrow*.

Generally, the larger the airgun volume and the larger the air pressure, the larger the pulse pressure. The pressure used at Northstar was nominally 2000 psi (13.8 MPa). When several guns are relatively close together and fired simultaneously, as they were for the 1996 Northstar seismic program, the individual pulses add together to increase the total pressure pulse amplitude.

The underwater sounds from the array of 11 airguns were measured under several conditions of distance, water depth, and aspect. Sounds from single airgun operations were also measured. The single airgun results are described first, followed by full array results. Finally, the results of measuring the sounds from a partial array of six airguns (a subarray) are presented. Arrays with less than 11 operating airguns were used occasionally during the 1996 Northstar program.

Single Airgun

Characteristics of sounds from a single 120 in^3 airgun were relevant because only one airgun was operating during some of the line changes and during OBRL work (Ocean Bottom Receiver Localization), as described in Chapter 2. A single airgun was also used at the start of a ramp-up to full array operation. In addition, a comparison of the levels from a single airgun with the levels from a full or partial array shows whether the sounds of individual airguns add coherently when operated in an array (i.e., whether the received levels increase by 6 dB when the number of airguns doubles).

Pulse sounds from a single airgun were recorded from *La Brisa* at anchor in water 12 m deep on 14 August. The tracks of the source and of *La Brisa* are shown in Figure 3.5. The source was moving WNW except near the end, when it turned back toward the ESE. Figure 3.6 shows both the pressure waveform and the pressure spectral density of the pulse that occurred at the closest point of approach (CPA) to the receiving hydrophone, which was at range 33 m. The peak pressure level in this pulse was 186 dB re 1 µPa, the rms pulse level was 173 dB re 1 µPa, the pulse energy was 161 dB re 1 μPa^2-s, and the pulse duration was 56 ms. (Pulse duration is the interval containing 90% of the pulse energy, as described in §3.2.) The pulse spectrum shows that sound energy peaked within 8-Hz frequency bands centered at 50 and 80 Hz.

Figure 3.7 shows the rms pulse pressure levels vs. distance for the opening range (stern aspect) phase of the run whose track is shown in Figure 3.5. The data were recorded between 15:19 and 16:16 ADT at ranges 33 to 6400 m. The water depth was 12 m at the receiver and varied from 11 to 13.8 m at the airgun source. The fitted equation (given in the figure caption) includes a forced cylindrical spreading loss term of -10*log(R) and a loss term of 4.8 dB/km. The sounds from a single airgun propagate omnidirectionally. Aspect is not expected to be a significant factor for single-airgun sounds except insofar as there may be shadowing at bow aspect by the vessel towing the airguns.

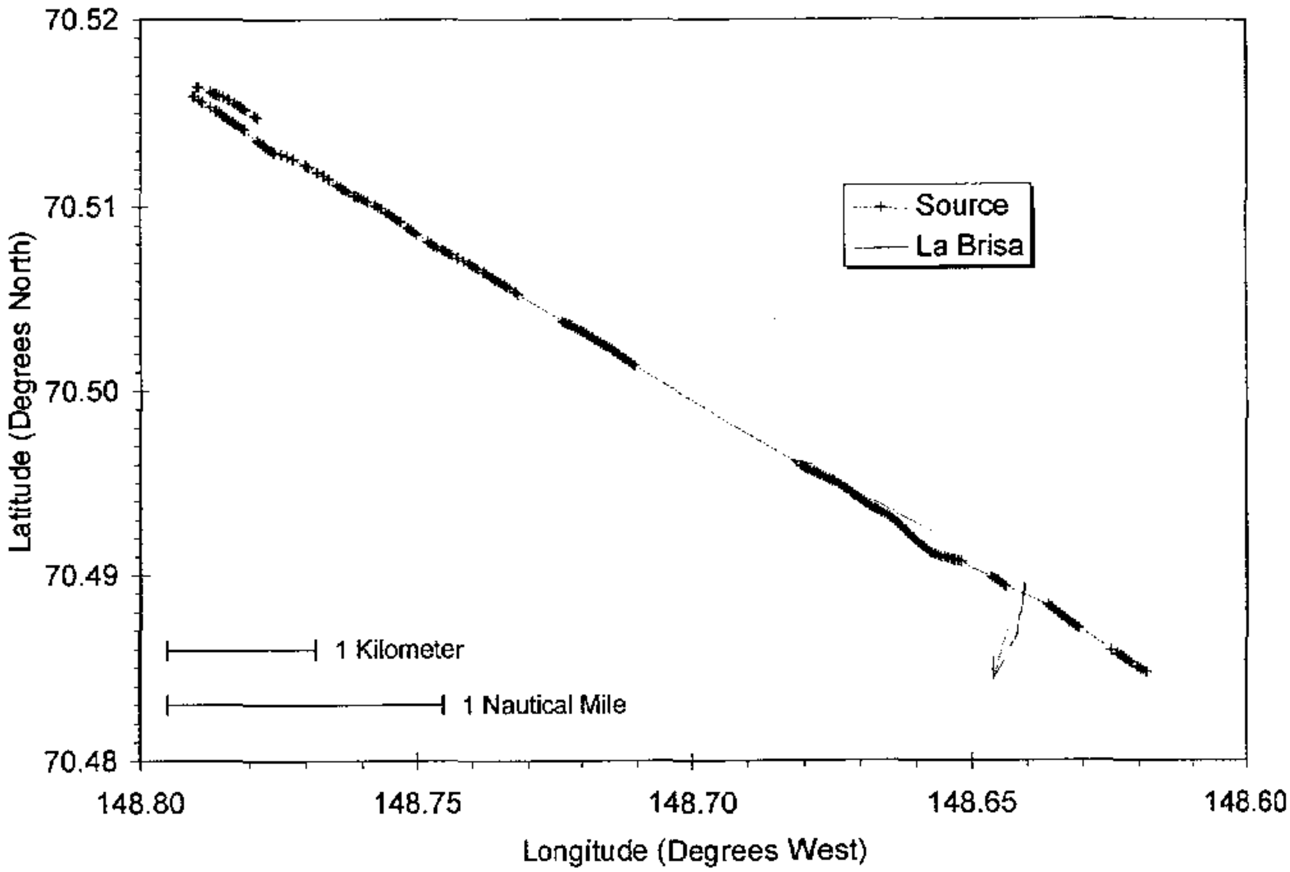


FIGURE 3.5. Track of seismic source vessel *Point Barrow* operating a single 120 in^3 airgun past *La Brisa* on 14 August 1996, 15:20-16:13 ADT, water depth 12 m at hydrophone, airgun depth 3.5 m, hydrophone depth 9 m, source vessel traveling from ESE to WNW. Latitude and longitude are in decimal degrees.

Received Levels.—The received levels (rms pulse pressure) from the full 11-airgun array were recorded at short ranges on 15 August. Recording vessel *La Brisa* was anchored in water 10.5 m deep at a position close to a regular production survey line along which source vessel *Point Barrow* would travel while towing the airguns. Figure 3.8 shows the survey line, which was oriented from SSW to NNE, relative to *La Brisa*'s positions. The water depths at the source were 7.1-10 m for the approaching phase of this run and 10.1-11.4 m for the opening range phase. Figure 3.9 shows both the pressure waveform and the pressure spectral density for the airgun sound at the CPA distance of 116 m. The peak pressure level in this pulse was 205 dB re 1 µPa, rms pulse level was 198 dB re 1 µPa, pulse energy was 183 dB re 1 μPa^2-s, and pulse duration was 32 ms. The pulse spectrum shows that sound energy peaked in the 8-Hz bands centered at 56 Hz, 160 Hz, 280 Hz and 360 Hz.

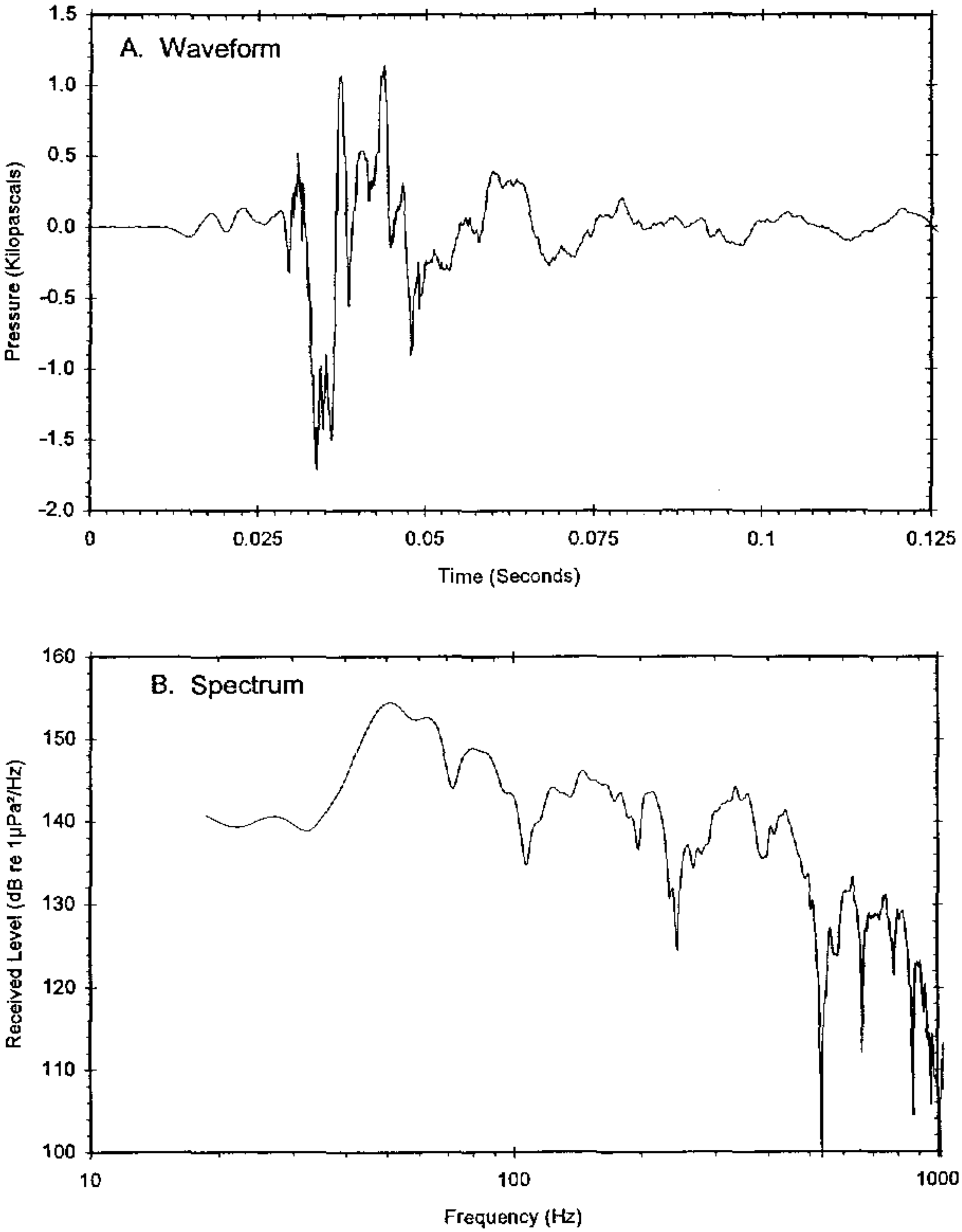


FIGURE 3.6. Waveform (A) and spectrum (B) of pressure pulse from a single 120 in³ airgun at 33 m distance, 14 August 1996. Recording location and depths were as shown in Fig. 3.5. For (B), averaging time was 0.125 s and analysis bandwidth was 8 Hz.

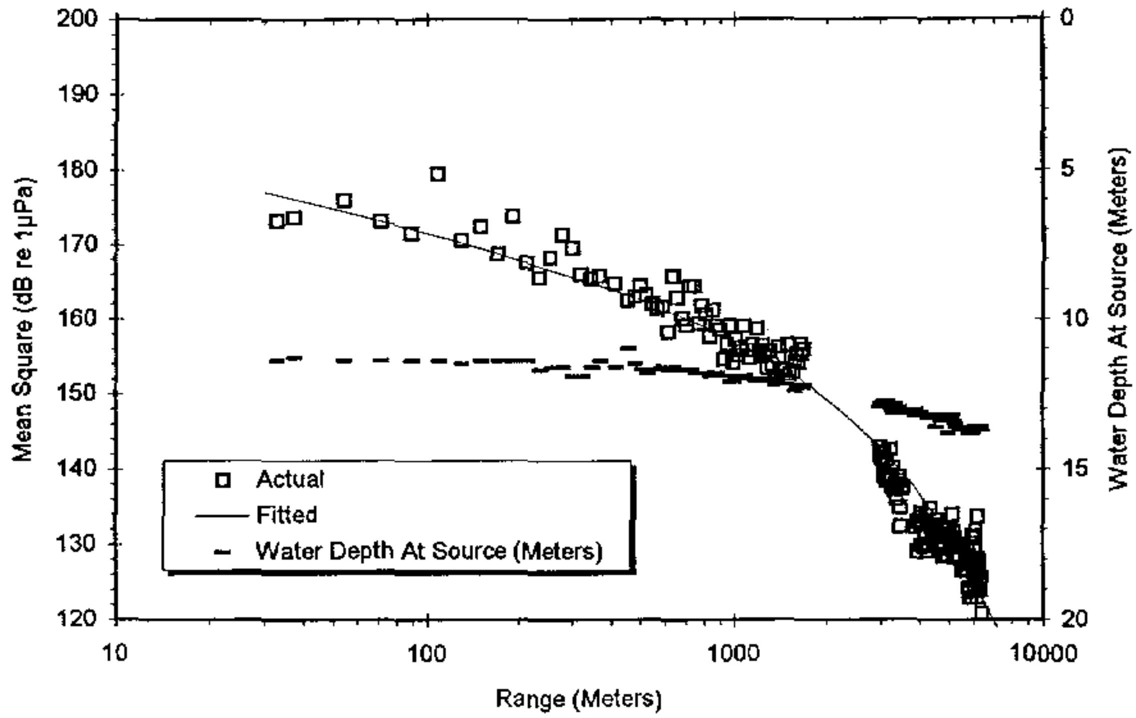


FIGURE 3.7. Received levels of pulses from the single 120 in^3 airgun measured as the source vessel was moving away to the WNW on 14 August 1996 (see Fig. 3.5). The fitted line corresponds to the equation

RL = 161.9 - 10*log(R) - 4.8*R

(R in km, RL in dB re 1 µPa). Received levels are the rms pressure pulse levels (see text). Water depth at the airgun array is also plotted.

Also shown in Figure 3.9B is the predicted spectrum of this airgun array (Painter 1996) based on 11 airguns in the array at a depth of 4 m. This estimate is for the farfield in the vertical direction (beneath the array) and includes the surface reflected energy. The differences in level and shape between the predicted array spectrum level and the measurements shown in Figure 3.9B are caused by propagation in the water channel, as discussed in §3.4.

Figure 3.10A shows the 35 received rms pulse levels from the full airgun array during the approaching phase of the run shown in Figure 3.8. Also shown is a fitted curve for which a cylindrical spreading term, -10*log(R), is forced into the best-fit model. The reason for forcing the cylindrical spreading term is discussed in §3.4, where the propagation properties of the Northstar area are analyzed. The equation, given in the caption, is most useful for distances within the measurement ranges, 158-1647 m. Except during the closest portion of the measurement run, the receiving hydrophone was very close to bow-aspect relative to the source vessel and airgun array. The -12.9 dB/km coefficient of R accounts for absorption and scattering losses and explains the downward turn in the best-fit curve at the longer ranges. This is typical of shallow water sound propagation; the depth at the location of the airgun

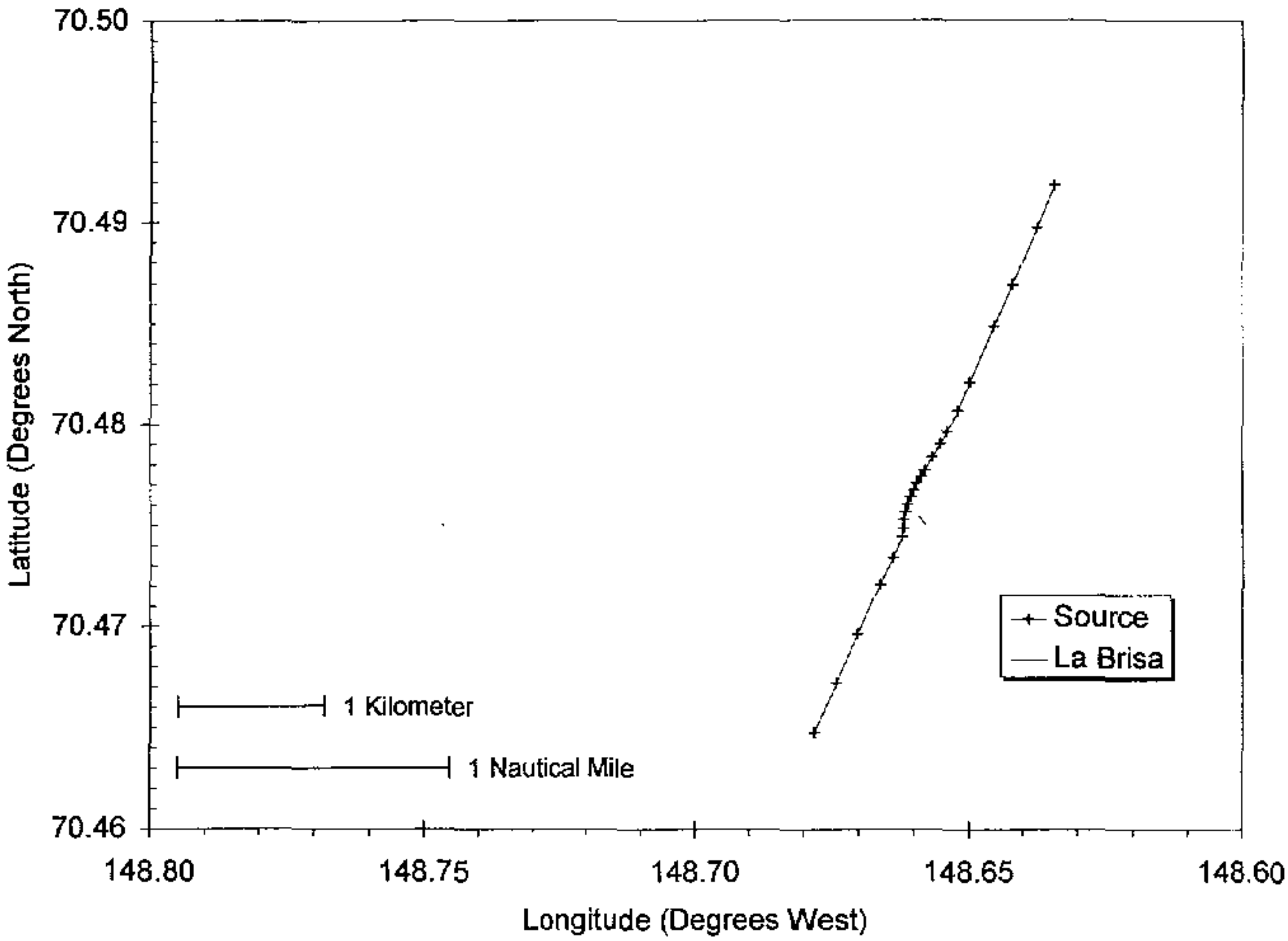


FIGURE 3.8. Track of seismic source vessel *Point Barrow* towing the operating airgun array (11 airguns) past recording vessel *La Brisa* during full airgun array recording on 15 August 1996, 10:00-10:40 ADT, water depth 10.5 m at hydrophone, hydrophone depth 9 m, source vessel traveling from SSW, heading 030° T. *La Brisa* moved slightly on its anchor mooring. Latitude and longitude are in decimal degrees.

array was near 7 m at the longer ranges and increased to 10 m as the source vessel approached the receiving hydrophone.

Figure 3.10B shows the 46 rms pressure pulse levels during the opening range phase of the run shown in Figure 3.8. In this case, all except the closest measurements were near stern-aspect. The ranges were 177 to 2113 m. Again forcing cylindrical spreading, the fitted equation given in the Figure caption has an absorption/scattering loss coefficient of -5.4 dB/km. This is indicative of less loss than was occurring during the "approaching" phase (*cf.* Fig. 3.10A, where loss was -12.9 dB/km) . This difference is probably related to the deeper water at the source and correspondingly lower bottom interaction during the outbound phase: water depth about 7-10 m during the approach vs. 10-11.5 m during the outbound phase.

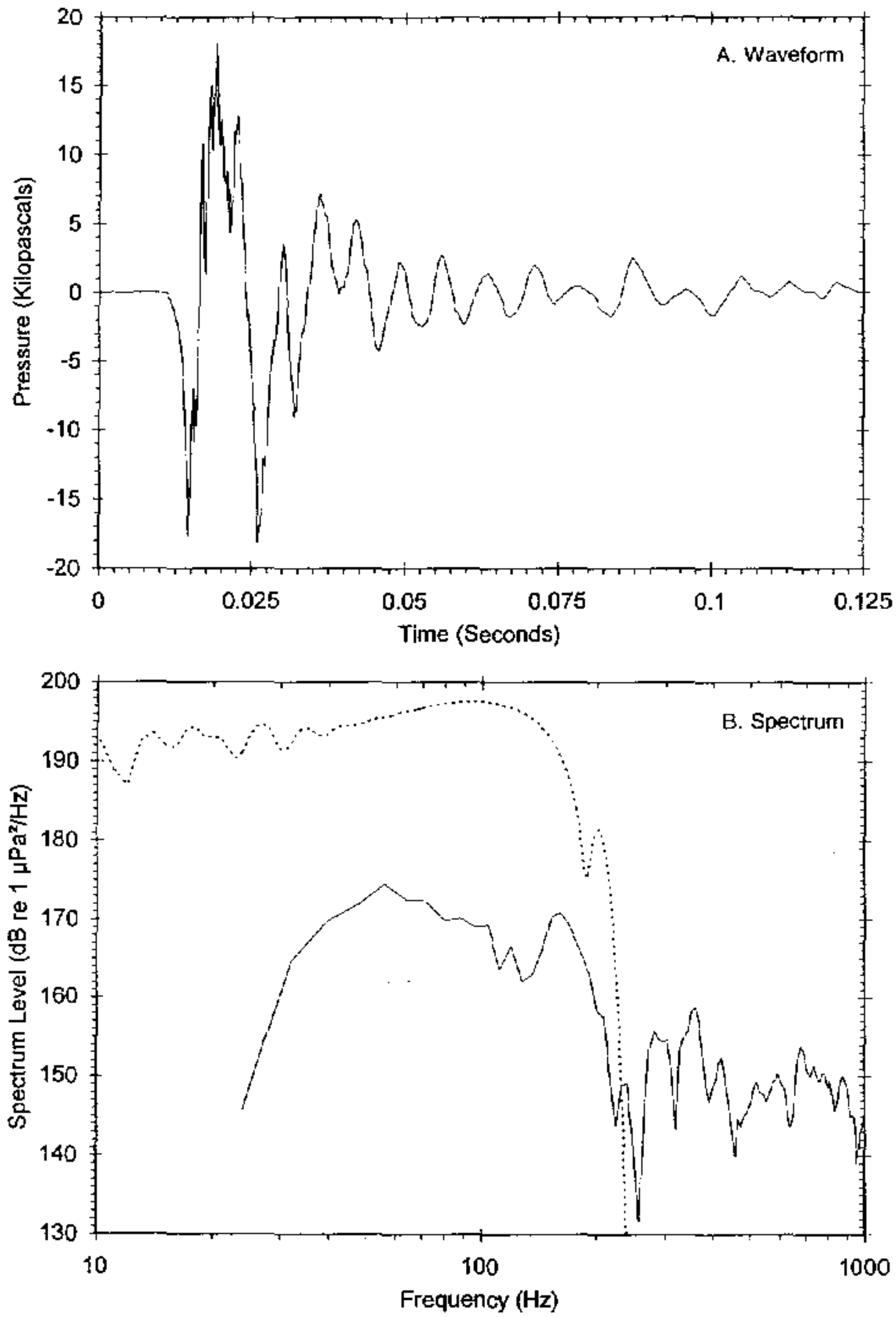
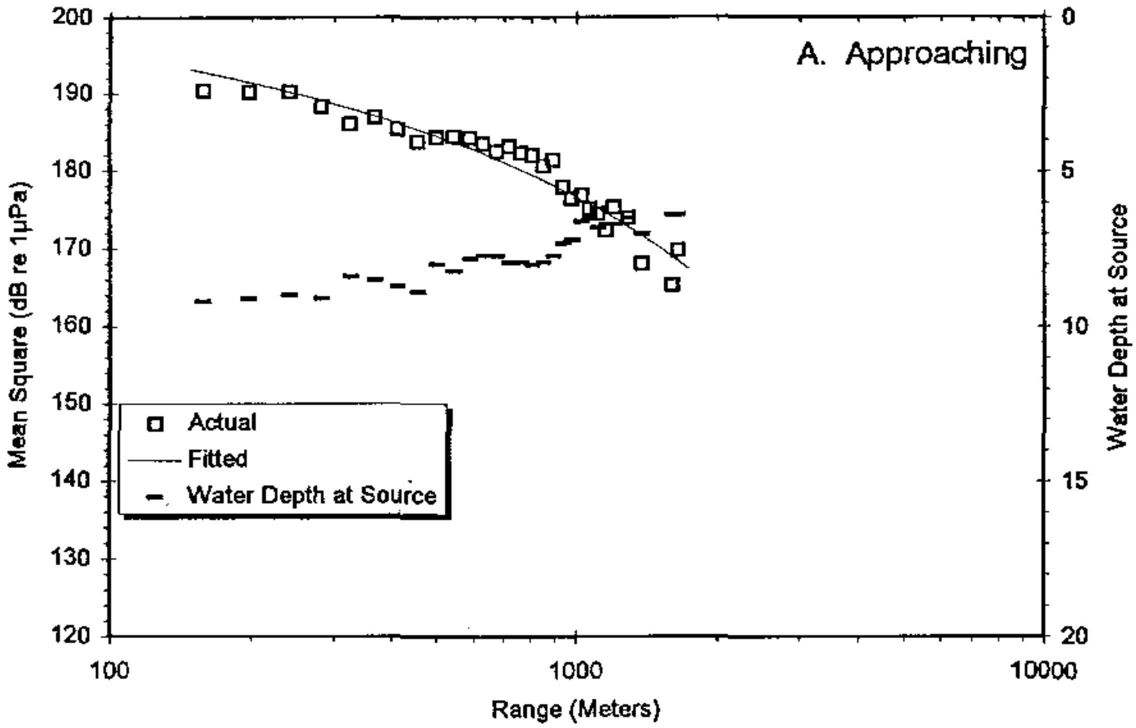


FIGURE 3.9. Waveform (A) and spectrum (B) of pressure pulse from the full 11-airgun array at 116 m distance, 15 August 1996. Dotted line in (B) shows the predicted source spectrum for the array at depth 4 m (Painter 1996). Recording location and depths were as shown in Fig. 3.8. For (B), averaging time was close to the pulse length, 0.125 s and analysis bandwidth was 8 Hz.



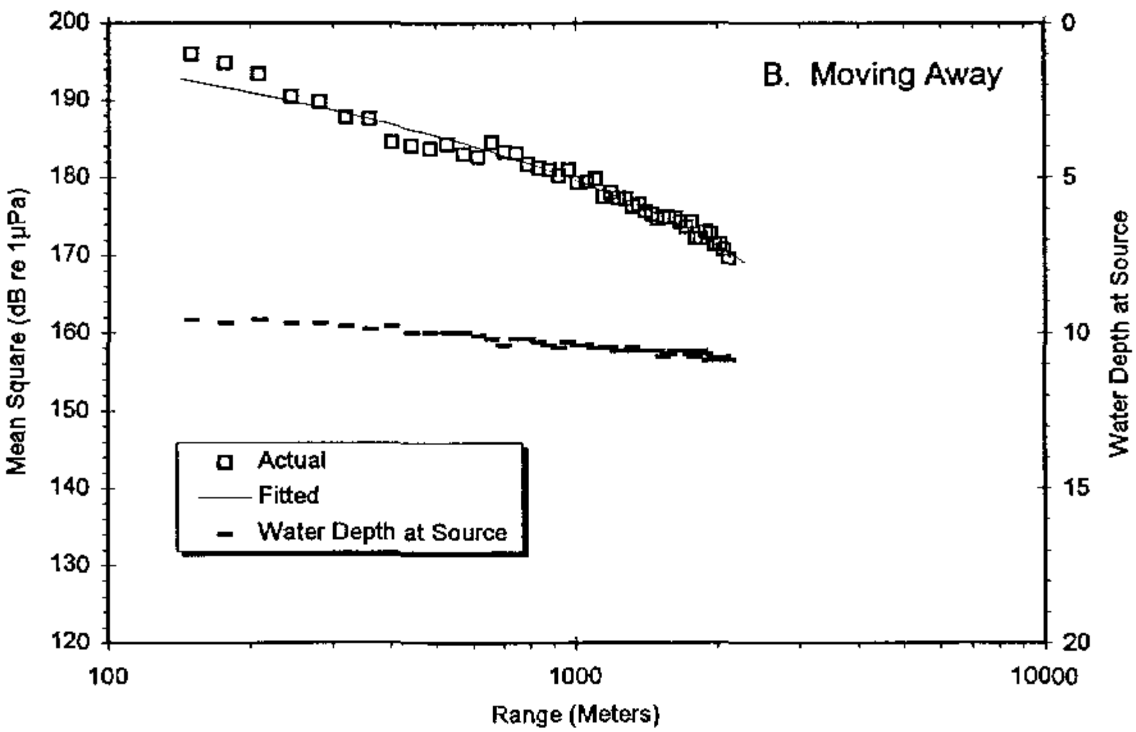


FIGURE 3.10. Received levels of pulses from full 11-gun array measured as the source vessel was ***(A)*** approaching from the SSW, water depths 7-10 m, and ***(B)*** moving away to the NNE, water depths 10-11.5 m, on 15 August 1996 (see Fig. 3.8). The fitted lines correspond to the following equations:

(A): RL = 188.1 - 10*log(R) - 12.9*R

(B): RL = 185.1 - 10*log(R) - 5.4*R

(R in km, RL in dB re 1 µPa). Received levels are the rms pressure pulse levels (see text). Water depth at the airgun array is also plotted.

The deeper water supports propagation of lower frequencies, which are important components of airgun pulses.

Figure 3.11 shows the predicted far-field azimuthal radiation pattern of the full 11-airgun array at four frequencies. Urick (1983:54*ff*) discusses beam pattern computation for arrays of elements. At 50 Hz the array is essentially omnidirectional. At 100 Hz the beam aspect radiation level is about three decibels less than the level at endfire (ahead or astern). At higher frequencies the array directionality increases, as manifest by the peaks and nulls in the azimuthal pattern (Fig. 3.11). However, the pulses contain little energy at frequencies above 150 Hz.

Levels for Full Array vs. Single Airgun.—The constant term in the fitted equation for the single airgun sound, 161.9 dB re 1 µPa, is about 23 dB less than the constant term

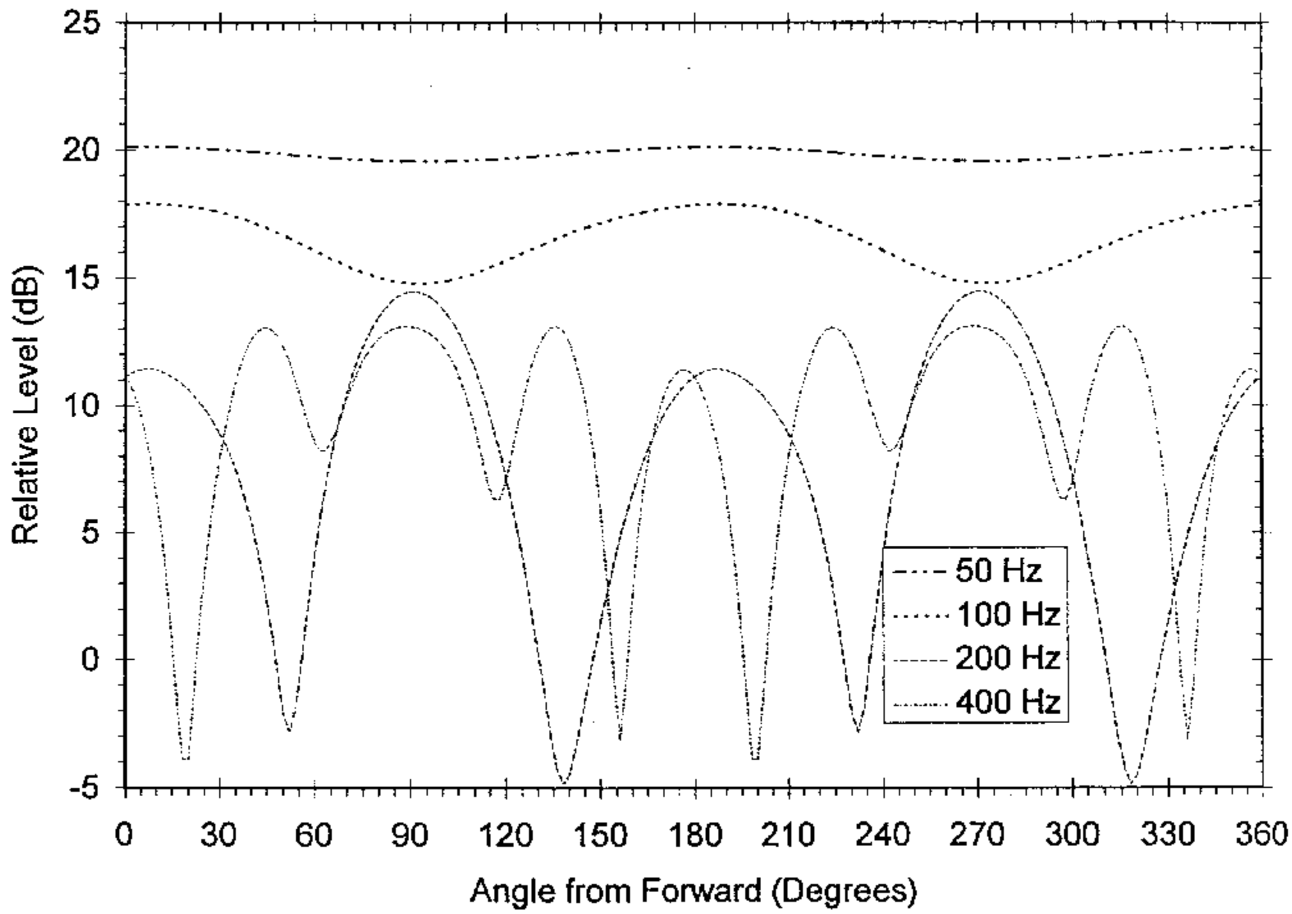


FIGURE 3.11. Predicted azimuthal patterns at 50, 100, 200 and 400 Hz for the full 11-airgun array used at Northstar. These patterns presume the receiver is in the farfield, or beyond 50-100 m.

in the equation for the full array, stern aspect, 185.1 dB. To the extent that the measurement conditions were close to the same, this difference is indicative of the difference in source levels for a single airgun vs. the full array. This 23 dB difference implies that the airgun sounds are adding coherently, or at a rate of 6 dB per doubling of the number of airguns. For such coherent addition, the idealized difference between 1 airgun and 11 airguns would be 20*log(11/1) = 21 dB.

Source Levels for Full Array.—To estimate the effective source level of the full 11-airgun array, it is necessary to take account of transmission loss effects. Therefore, the "Source Level" topic is deferred to section 3.4. That section also includes estimates of the radii corresponding to certain specific received sound levels (e.g., 190, 180 and 160 dB re 1 μPa), which are of interest in relation to potential effects on marine mammals (*cf.* Chapters 4, SEALS, and 5, WHALES).

Partial Arrays

Several configurations of reduced airgun arrays with four to nine airguns operating were measured during the field season. These measurements were obtained because a partial array was used for a small fraction of the production shooting, and because a partial array was sometimes operated during line changes.

Received levels from a six-airgun "partial" array as it moved away are shown in Figure 3.12 along with the least-squares fitted equation with cylindrical spreading forced, i.e. -10*log(R) term included. These data were collected with the array at a depth of 3.5 m in water 9 m deep; the receiving hydrophone was at a depth of 8 m. The difference between the intercept constant in the full array equation (see Fig. 3.10B, 185.1 dB) and in the equation for this partial array (180.6 dB) is 4.5 dB. The predicted decrease under the assumption of coherent addition is given by 20log(6/11) = -5.3 dB. The difference between the predicted and measured decrease in level is less than one decibel. Subtracting the regression equation intercepts corresponds to comparing the measurements at short range. If the regression equations are used to estimate the received levels from the full 11-gun and 6-gun arrays at range 200 m, the difference in the estimates is 5.2 dB. That difference is very close to the predicted 5.3 dB decrease assuming coherent addition of the airgun elements in the array.

Summary

Most of the pulse level measurements given above are rms levels. Rms levels are, in effect, average levels over the duration of the seismic pulse. As shown in Figure 3.3, rms levels are several decibels less than peak levels. The difference between the two measures averages about 10 dB.

Figure 3.13 compares the rms pulse pressure levels in relation to range for varying numbers of airguns, based on data from Figures 3.7, 3.10B and 3.12. Comparisons should be made for the shorter ranges, say <500 m, to avoid marked sound propagation effects.

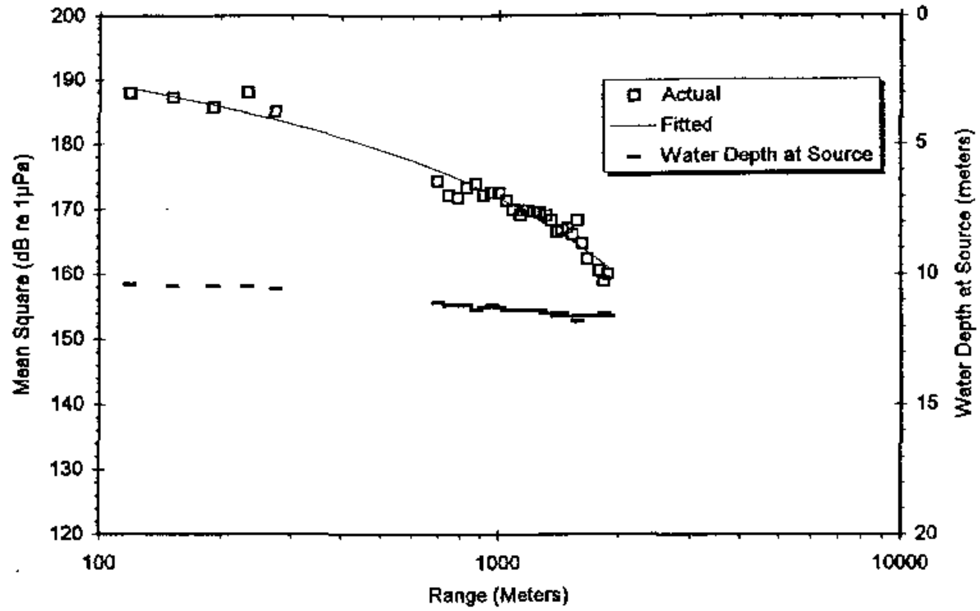


FIGURE 3.12. Received rms pulse levels vs. range (moving away) for array NGC #3, a 6-gun partial array. The line fitted to these 31 points corresponds to the equation

RL = 180.6 - 10*log(R) - 8.9*R

(R in km, RL in dB re 1 µPa). Water depth at the airguns is also plotted.

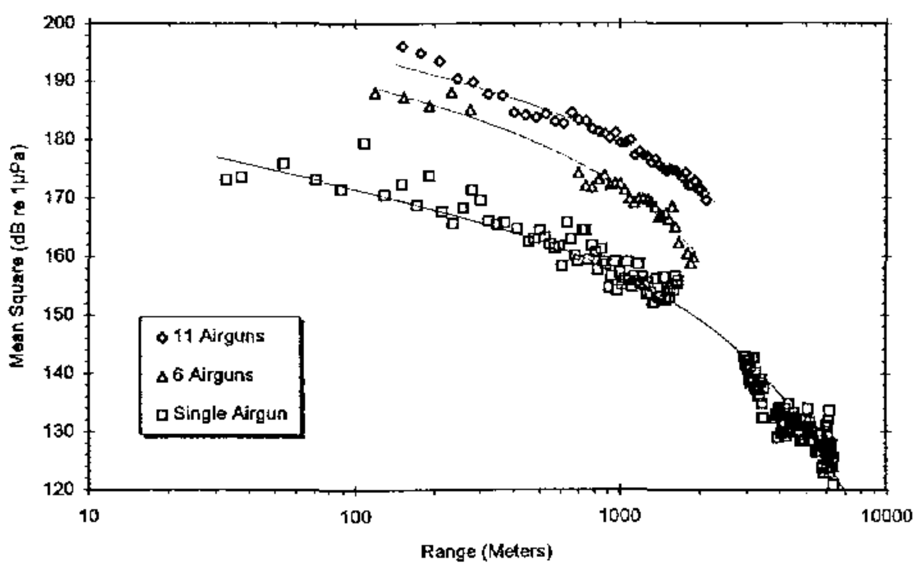


FIGURE 3.13. Received rms pulse levels vs. range for 11, 6 and 1 airguns. All measurements came from the "outbound" operational condition. The fitted lines all have the same spreading loss term, -10*log(R), but differing intercept constants depending primarily on the source levels and differing linear range coefficients (dB/km) depending on the water depths of the measurements.

The results affirm the hypothesis that, for the size of airguns (120 in^3) and array geometry (5 m square) used at Northstar, the sound pressures from the individual airguns added coherently. The pressures will double for each doubling of the number of airguns, which is equivalent to saying that the sound levels will increase by six decibels for each doubling of the number of airguns. Purely coherent addition would result in the 6-airgun array having a pressure level 5.3 dB less than the full array, i.e., 20*log(6/11) = -5.3 dB. The actual differences were -4.9 dB for range 100 m and -5.2 dB for range 200 m. Correspondingly, the single airgun pressure level would be expected to be 21 dB less than the full array, i.e., 20*log(1/11) = -21 dB. The actual differences for ranges 100 and 200 m were both -23 db.

3.4 Transmission Loss and Received Levels of Seismic Pulses

This section begins by describing sound transmission loss at short ranges in and near the Northstar Unit. This description is based on received levels of airgun pulses (single gun and full array) at different ranges and on variations in the frequency content of the received pulses. Secondly, we use the information about transmission loss at short ranges to estimate the source levels of the airguns and to estimate the radii where certain "standard" received levels (190, 180 and 160 dB re 1 µPa) would occur. Thirdly, we describe propagation of airgun pulses to receivers at long ranges (up to 67 km, or 36 n.mi.) in deeper water, mostly to the north or northeast of Northstar.

The effect of source depth on sound transmission was not addressed in this field study as the airgun array depth was the same for all our measurements: 3.5-4 m. However, the effects of surface reflections are well known, giving rise to the Lloyd mirror effect (Richardson et al. 1995:73). The effect is most notable at low frequencies, when the depth is less than ¼-wavelength; the surface reflection interferes with the direct sound paths and sound transmission is poor. For a source depth of 3.5 m, frequencies below about 100 Hz will be severely attenuated during horizontal transmission. This is important because much of the airgun energy is at frequencies from 40 to 150 Hz (Fig. 3.6B, 3.9B).

Transmission Loss Features Near Northstar

Single Gun Data.—On 14 and 17 August, hydrophones deployed from *La Brisa* were used to monitor the levels of a single airgun in two different depths of water. On the 14th, the water depth at the source was 11-13 m, while on the 17th the depth was about 5 m. The frequency content of the pulses was different in those two water depths and the decrease of the rms pulse levels with range was also markedly different. These two data sets support some conclusions about the effect of water depth on the ranges where received sound levels would be expected to diminish below various specified levels that may be relevant to marine mammals, e.g., 190, 180, and 160 dB re 1 µPa.

Figure 3.14 compares the power spectra near CPA for each of the two data sets; the ranges were 128 m and 129 m on the 14th and 17th, respectively. Two points about this comparison are significant. First, there is a sharp decrease in the level below about 40 Hz for both cases. A shallow water channel cannot support propagation of energy below a

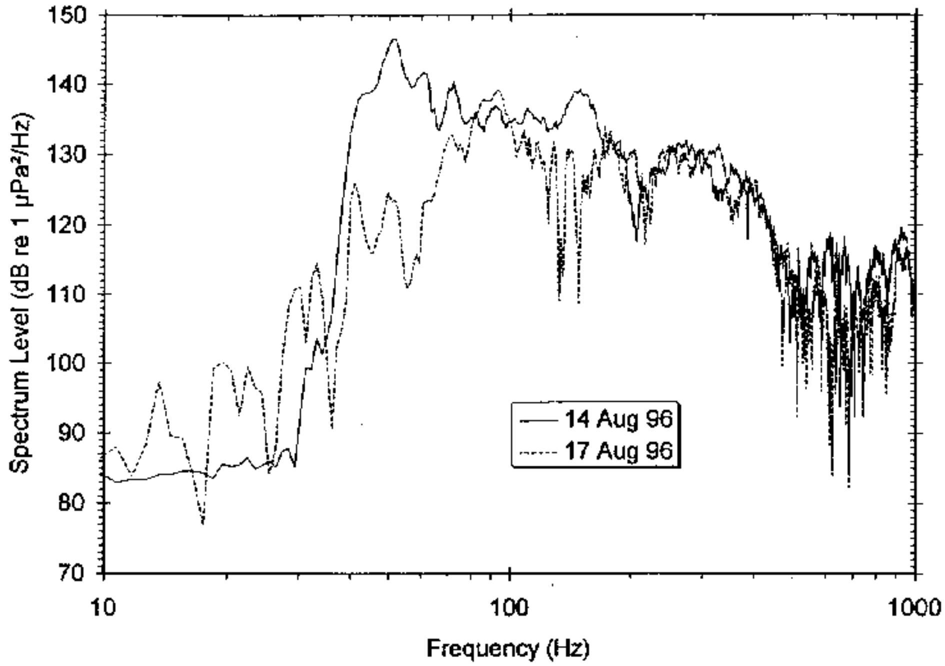


FIGURE 3.14. Power spectra from single airgun at close-range: 14 Aug., distance 128 m and water depth 12 m; 17 Aug., distance 129 m and water depth 5 m. Averaging time was 1 s; analysis bandwidth was 1 Hz.

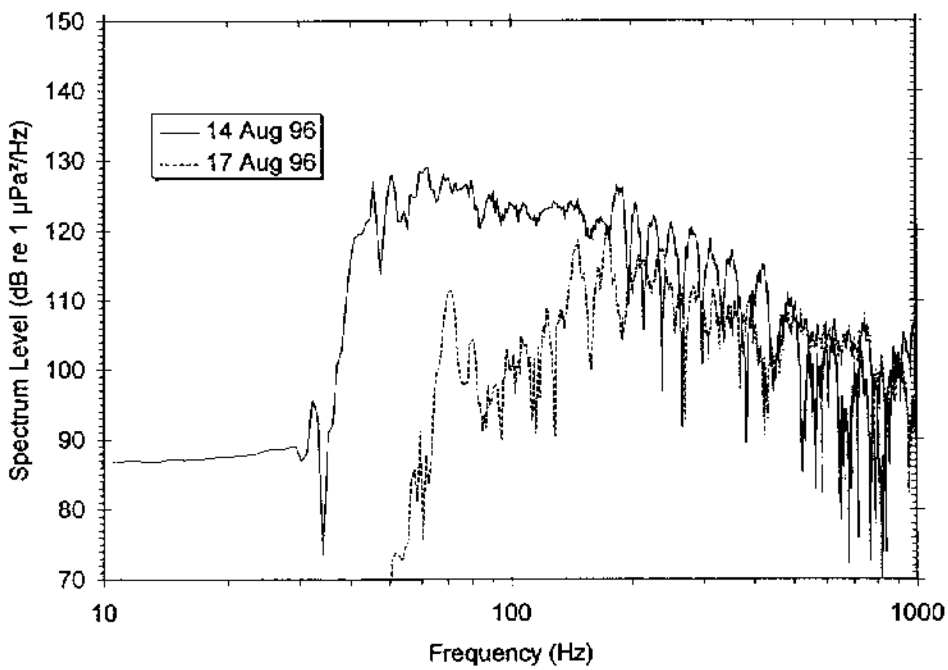


FIGURE 3.15. Power spectra from single airgun at moderate distances: 14 Aug., 910 m; 17 Aug., 820 m. Otherwise as in Fig. 3.14.

critical frequency to horizontal ranges exceeding a few times the water depths. This critical frequency is determined by the water depth and the properties of the bottom. For the simple case of a shallow water layer over a single bottom layer, this frequency is inversely proportional to the water depth (Brekhovskikh 1960). Since the water depth on the 17th was about half that on the 14th, the cutoff frequency on the 17th should have been about twice that on the 14th. Note that the level of the spectrum for the 17th decreased below 70 Hz, and then decreased again, steeply, at 40 Hz. In slightly deeper water on the 14th, there was a steep decrease below 40 Hz, but not at 70 Hz. The difference between the two spectra in the 40-70 Hz range is essentially caused by this waveguide effect.

This behavior of the received levels at low frequencies can be seen even more clearly in Figure 3.15, which compares the spectra at ranges of 910 and 820 m on the 14th and 17th. A sharp decrease in level is quite evident below frequencies of about 40 Hz on the 14th and 70 Hz on the 17th. The ratio of observed cutoff frequencies is not exactly the ratio of water depths (12 m vs. 5 m). This small "discrepancy" probably occurred because the actual environment, e.g., bottom conditions, is more complicated than allowed for by the simple model suggested above.

It is also clear from Figure 3.15 that the total energy level of the received signal is lower in the shallower water, given that the spectral levels at many frequencies are lower on the 17th than those in the slightly deeper water on the 14th. This is more evident in Figure 3.16, which compares the behavior of the rms pulse levels as a function of range for the two data sets. The levels received in 5 m water depth on the 17th decreased much more rapidly with range than did those received in 12 m water depth on the 14th. This result is consistent with the data in Figure 3.15.

The most important implications of these data are that both the frequency content of the propagating airgun signals and the rate of fall-off with range are significantly affected by the water depth in the shallow waters of the survey area. In particular, as water depth decreases, there is ▸ an increase in the cutoff frequency (below which signal components cannot propagate to significant distances) and ▸ an increase in the rate at which the received levels diminish with increasing range.

In Figure 3.16, the data from each day are divided into two subsets corresponding to the measurements while the source vessel *Pt. Barrow* was approaching the recording vessel *La Brisa* ("Before CPA") and while receding from *La Brisa* ("After CPA"). This was done because there is a suggestion in the data of a dependence on aspect. Because the single gun is expected to be omnidirectional at the frequencies which dominate the signal, we speculate that the vessel towing the airgun, the *Pt. Barrow*, may have shadowed the sound to some extent. This could account for the somewhat higher received levels after than before CPA on 14 August. However, the pronounced difference in the opposite direction on the 17th must have been caused by a propagation difference along the corresponding track segments.

Full Array Data.—One of the important considerations in this project is the amount of energy that propagates from the airgun array into the deeper water north of the survey

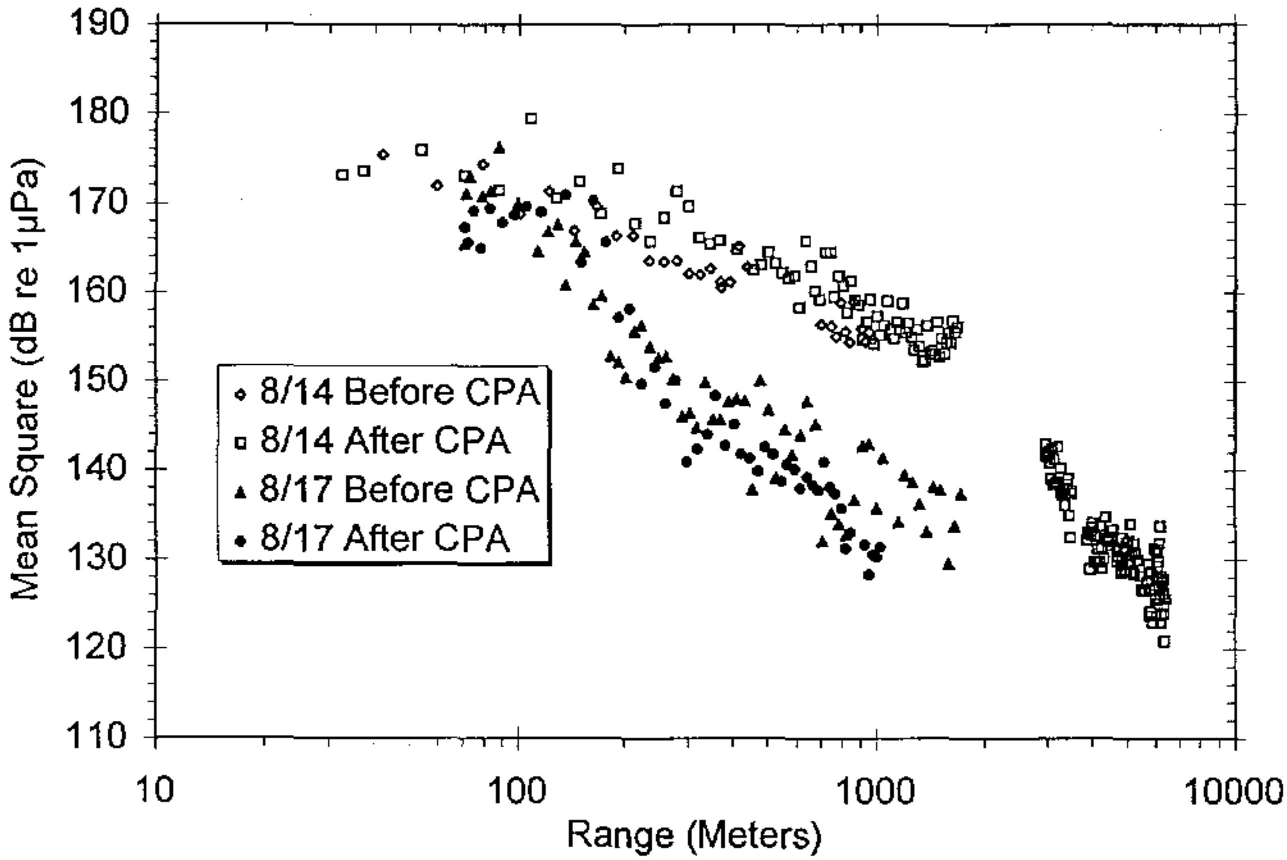


FIGURE 3.16. Rms pulse levels vs. range for single 120 in^3 airgun operating in water ~12 m deep (14 Aug.) and 5 m deep (17 Aug.).

area. Hence, it is important to examine the longer range data when the full array was operating. The data considered here were collected on 15 August 1996 in the morning at ranges up to 2 km and in the afternoon at ranges to about 12 km. Spectra from representative pulses are shown in Figure 3.17 at selected ranges. Two features of the spectra are significant here:

- The low frequency cutoff observed in the single gun data can be seen in these spectra as well. The evolution of the full-array spectra from the shortest range of 115 m out to 2 km shows the development of the same sharp drop as was seen in the single gun data. At the two longer ranges, the low frequency cutoff can still be seen.
- The effective bandwidth of the spectra decreases with increasing range. At 115 m the dominant frequencies in the received pulse extend from about 30 to 200 Hz, while at 2 km the dominant frequencies extend from about 50 to 150 Hz. This

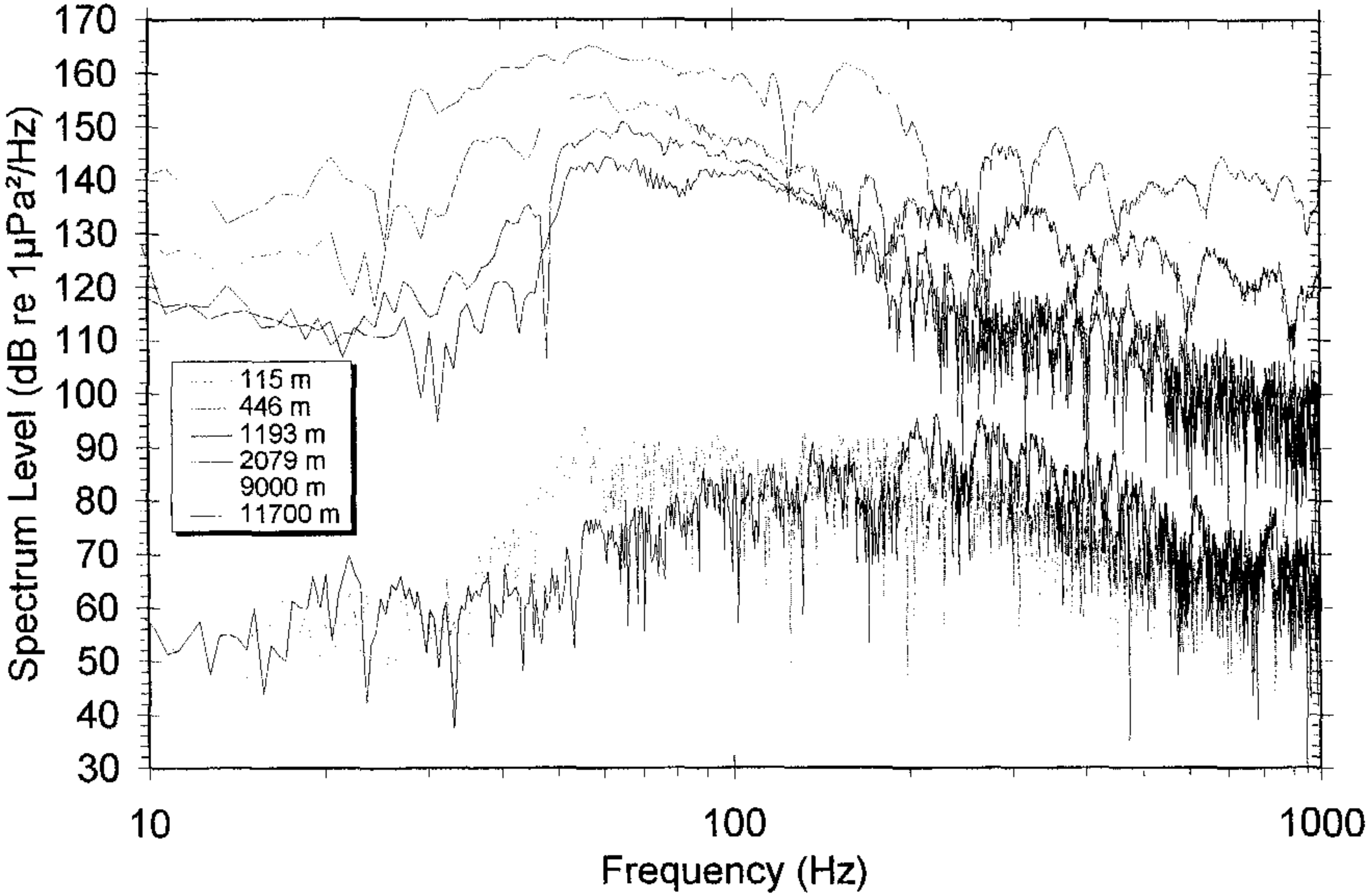


FIGURE 3.17. Representative power spectra at six distances from the 11-airgun array, 15 Aug 1996. Averaging time was 1 s and analysis bandwidth was 1 Hz for the top four spectra; 2 s and 0.5 Hz for the lowest two spectra.

amounts to a change of about a factor of 1.7 in the effective bandwidth. In the simple case of a flat spectrum, the acoustic power or energy is proportional to the bandwidth, which means that a factor of 1.7 change in bandwidth will change the sound level by 10*log(1.7) = 2.3 dB.

Effect of Water Depth on Received Level Radii.—In §3.3, it was shown that the expected difference in radiated level between the full 11-gun array and a single airgun is 21 dB. With this in mind, we can use the single gun data to illustrate the effect of water depth on the 190 dB, 180 dB and 160 dB radii for the full array; these radii may be relevant to marine mammals. To make such comparisons, regression lines were fitted to the data from the 14 and 17 August (Fig. 3.18, 3.19). The slopes of these lines are -15 dB/decade for the data from the 14^{th} and -21 to -30 dB/decade for the data from the 17^{th} (i.e., a reduction in sound level of 15 dB or of 21 to 30 dB per 10-fold increase in range).

Seismic pulses from the full 11-gun array are about 21 dB stronger at any specified range than are those from a single gun. Thus, the range at which sounds from a full 11-gun array diminish to 160 dB is about the same as the range at which sounds from a single airgun would diminish to 139 dB. The data from the deeper (12 m) water on 14 August imply that this level will be reached at 3.6 km (see Fig. 3.7), while the data from the shallower water on 17 August give a range of 0.6-1 km (see Fig. 3.19).

This example demonstrates that the water depth has a substantial effect on the received level at a given range and, hence, on the ranges where levels potentially relevant to marine mammals, e.g., 160 dB, 180 dB and 190 dB, will occur. We do not have acoustic measurements with the array operating in water much deeper than that on the 15^{th} (10 to 12 m). However, this analysis of the single gun data from two depths (~5 and 12 m) implies that, if the array did operate in deeper water, the received levels would change in two ways. First, the received levels would fall off more slowly with range. Second, the spectrum of the pulses as received at substantial distances would contain more low frequency energy. The expected change in the spectrum would occur because the waveguide cutoff frequency would be lower if the water were deeper. The airgun source is energetic at these lower frequencies and higher overall peak and rms levels would be expected.

This implies that, when comparing the apparent disturbance from various seismic surveys, it is important to account for two differences: water depth and the size and number of guns in the array. These two factors can cause significant differences in the received pulse levels at long ranges. For this physical reason (in addition to probable biological reasons), it is not possible to establish a single range beyond which migrating whales would not be affected by a survey. Surveys in deeper water or with larger arrays than were used at Northstar could be expected to produce significantly higher levels at equal or longer ranges than those shown here.

Transmission Loss Model.—Transmission loss in an underwater channel depends primarily on the depth of the channel and the loss of energy that interacts with its boundaries. If these boundaries are perfectly reflecting, the transmission loss will exhibit the

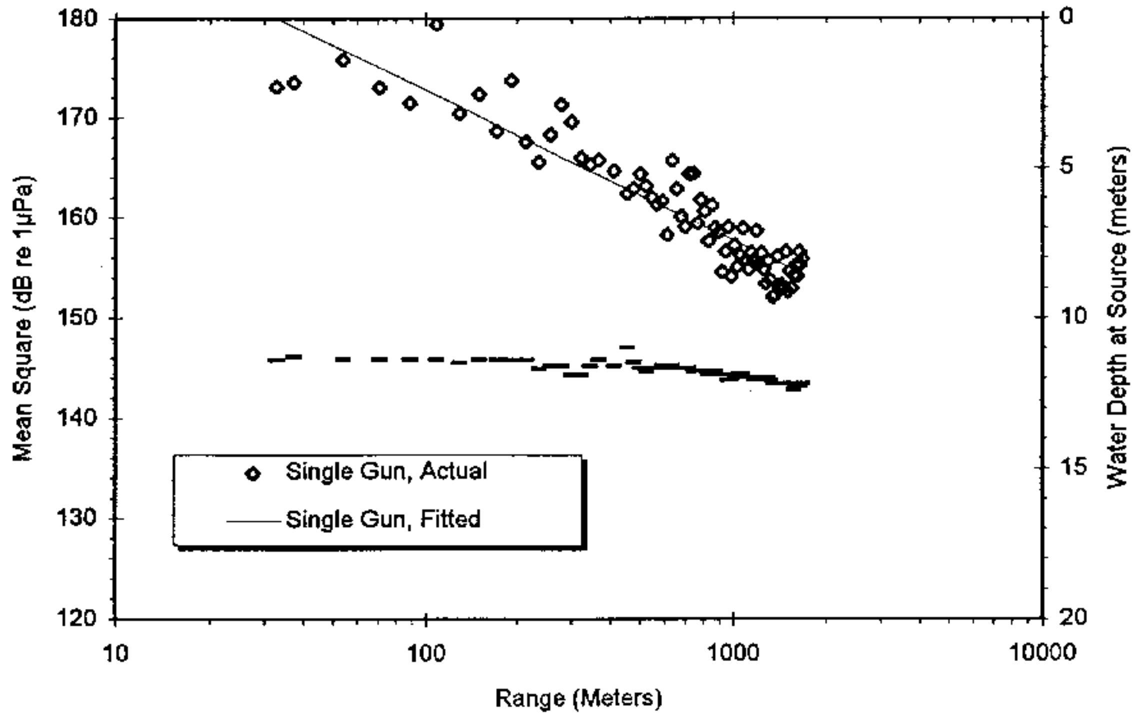


FIGURE 3.18. Rms pulse levels from a single airgun on 14 Aug. The line represents a least squares fit to the data. Water depth at the airgun is also plotted.

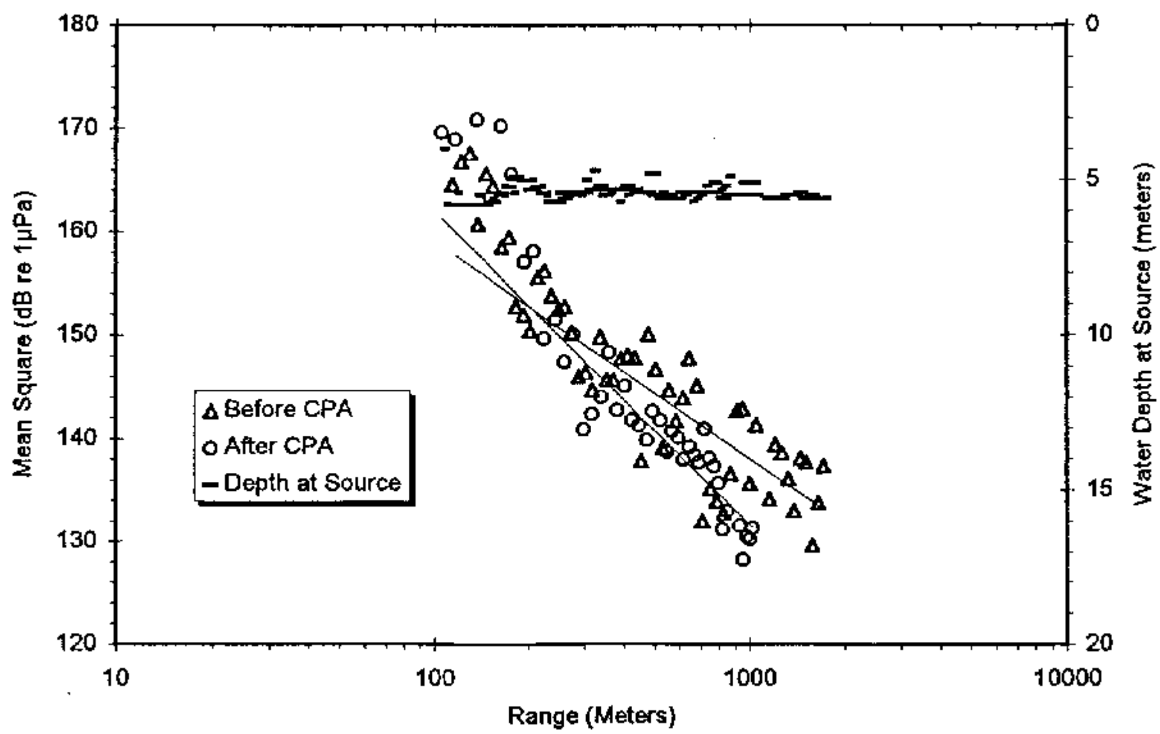


FIGURE 3.19. Rms pulse levels from a single airgun on 17 Aug. The lines are least squares regression fits based on the data from distances 200-600 m. Water depth at the airgun is also plotted.

cylindrical spreading mentioned in §3.3, which is expressed in decibels as -10*log(R), where R is the range from the source to the receiver. If the boundaries are not perfectly reflecting (which is the case for underwater channels), then other terms must be added that account for this loss. The following discussion explains how this modified transmission loss is expressed.

In the discussion above of the frequency spectrum of the airgun data, it was noted that shallow channels do not support the propagation of low frequency sound, and that the frequency below which the sound does not propagate depends on the water depth. Specifically, the shallower the channel, the higher this limiting frequency will be. There is a physical theory that explains this effect, and it depends upon a particular representation of sound propagation in such channels. This representation describes the sound as a function of frequency, range and depth, using mathematical quantities called normal modes (Brekhovskikh 1960; Frisk 1994; Richardson et al. 1995:60). In much the same way that a drum has preferred modes of vibration, so also does an acoustic channel. For a drum, these modes will depend upon the size and shape of the drum, as well as the tension in the drumhead. In the case of the acoustic channel, the modes depend upon the speed of sound in the channel, the channel depth, and the acoustic properties of the channel boundaries.

Assuming the simple model invoked to explain the low frequency cutoff in the pulse data (namely, a shallow water layer over a single bottom layer), the sound intensity of such a mode can be written as follows:

$$I = I_0 F(f, z_S, z_R, d)\frac{e^{-\alpha r}}{r} \qquad \text{Equation 1}$$

This expression includes a factor that depends on the source intensity I_0, frequency f, source depth z_S, receiver depth z_R, and water depth d; and another factor that depends on range r and boundary losses represented by a mode attenuation α. Note that the inverse proportionality between I and r implies that the modal sound levels, in decibels, will vary as -10*log(r), or cylindrical spreading. In general, the sound field will include some number of these modes, and the function F and the constant α will be different for each mode.

For the interpretation of the Northstar data, the most important characteristic of the modes is their dependence on frequency. Using the analogy of a drum, there is a lowest frequency at which the drum will vibrate that, again, depends on its size and the tension in its drumhead. Similarly, for the sound channel, there is a lowest frequency at which it can propagate energy to long ranges (where long ranges are equivalent to many times the water depth). So, for a particular mode, the function F is essentially zero below its characteristic frequency. The so-called lowest order mode is the one that determined the sharp rolloff in the pulse spectra discussed above; for the data from 14 and 15 August, this occurred around 40 Hz. The theory of these modes shows that, if the lowest order mode has a characteristic frequency of f_0, then the higher order modes will have characteristic frequencies of $3f_0$, $5f_0$, $7f_0$, and so on. For the data from 14 and 15 August, these frequencies would be 120 Hz, 200 Hz, 350 Hz, and so on. Since most of the energy in the pulses is below 150 Hz, or less, it follows that most of its energy is represented by the lowest order mode.

Since the data for received levels are in decibels, the above expression for a single mode, in decibels, would be

$$10\log(I)=A-10\log(r)-Cr$$

where A depends on the source level, frequency, source and receiver depths, and water depth, but not on range; C is related to the mode attenuation α. This is the form that was fitted to the data in §3.3.

A consistency test for this representation of the sound field can be made using the data from Figure 3.17. The range-dependence of the pulse spectra can be used to estimate the parameter C in the above expression. To do this, an average level around the spectral peak was taken from the spectra in Figure 3.17 for the ranges out to 2 km; these levels are given in the second column of Table 3.1. (The levels at the two longer ranges in Fig. 3.17 will be considered below.) In the third column, these levels are adjusted for the expected dependence on the log of the range. These adjusted levels, which should have a linear dependence on range, are plotted in Figure 3.20. The straight line is a least squares fit to the adjusted levels; its slope, which is the constant C, is 4 dB/km.

TABLE 3.1. Peak spectrum levels from Figure 3.17.

Event Time	Level (dB re 1 μPa²/Hz)	Level + 10 log r	Range (m)
10:26:50	165	185.6	115
10:29:41	158	184.5	446
10:34:28	150	180.8	1193
10:40:01	145	178.2	2079

Using this value of C and the specific form of the function F which, for the lowest order mode, is

$$F=\left(\sin\left(\pi\frac{z_S}{d}\right)\sin\left(\pi\frac{z_R}{d}\right)\right)^2$$

the value of the peak in the spectrum at 115 m can be used to estimate the peak at 1 m. The appropriate values of source, receiver and water depths are 3.5, 9, and 11 m, respectively. This results in an estimated source level of 193 dB re 1 (μPa-m)²/Hz. The peak of the spectrum from Painter's model (Painter 1996) (Fig. 3.9B) is 198 dB re 1 (μPa-m)²/Hz. This value involves the coherent addition of the direct and surface-reflected energy, so the equivalent source spectrum level of the free-field source itself is 192 dB re 1 (μPa-m)²/Hz. Thus, the estimate from the Painter model is only 1 dB different from the estimate based on the received spectra at various ranges and the above propagation model. This is additional confirmation that the mode description, based on the simple model of a water channel over a single bottom layer, is usefully accurate for short-range propagation in the Northstar area.

This single-mode model was used to estimate received spectrum levels for the two longer-range situations illustrated in Figure 3.17. This involves using the water depth at the receiver and at the source in the expression for F. Using this approach, levels at 9 and 11.7

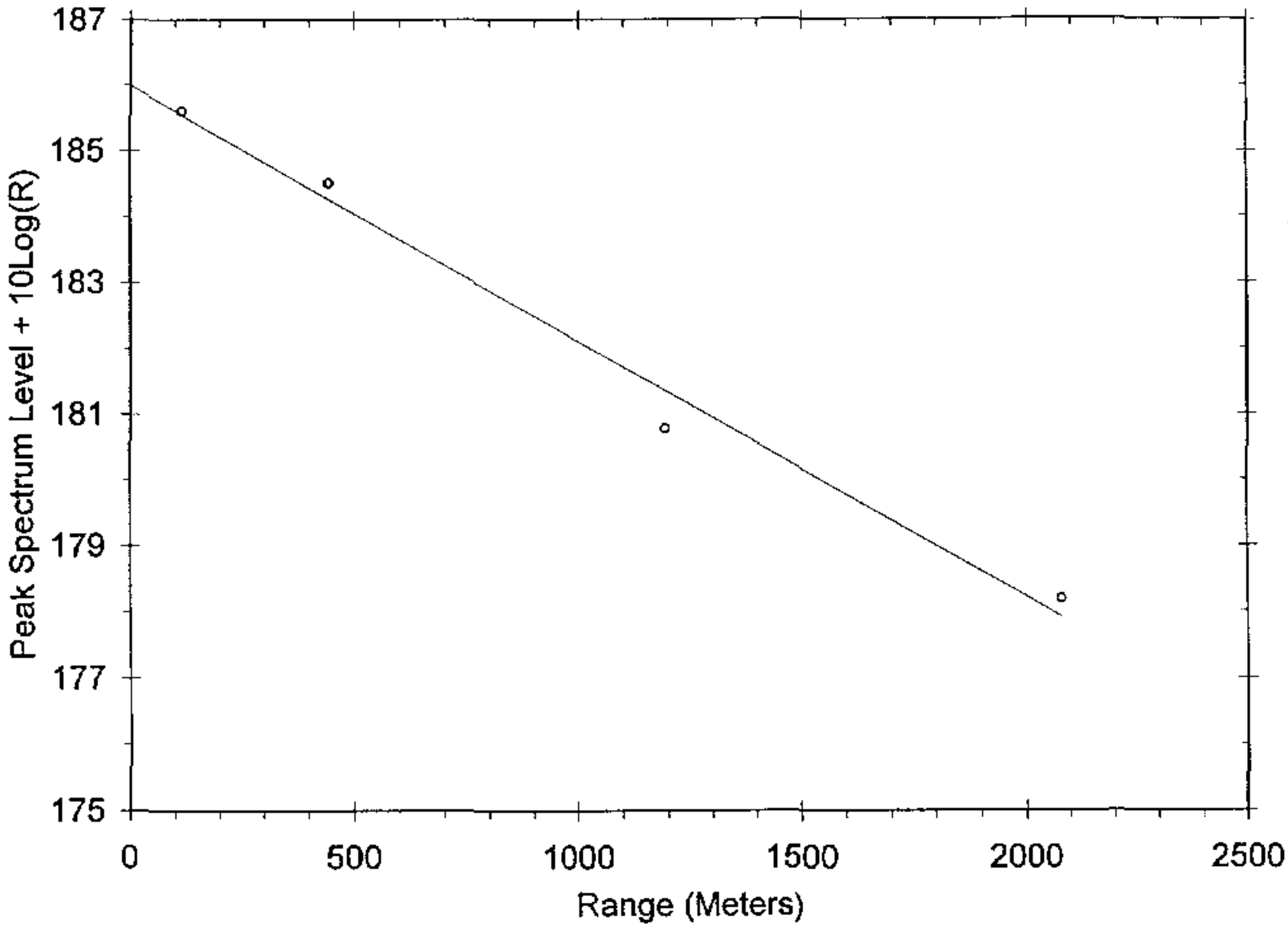


FIGURE 3.20. Least squares estimate of mode attenuation for 11-airgun array, 15 Aug 1996. The slope is -4 dB/km.

km are expected to be 116 and 104 dB re 1 μPa^2/Hz, respectively. The observed levels (Fig. 3.17) are 10-15 dB lower than predicted, meaning that this simple model is not adequate to represent propagation out to ranges of 9-12 km. This could be because the mode attenuation, which is determined by the bottom properties, varies along the track into deeper water.

A possible explanation for variable bottom properties could be the sporadic presence of shallow relic permafrost, i.e. ice-bonded subsea permafrost. This appears as higher-velocity strata in seismic records. These higher-velocity regions would refract sound waves and would result in better horizontal sound propagation. They could have the effect of deepening the sound channel, enhancing low frequency propagation compared to a highly absorptive, low-velocity bottom material. Neave and Sellman (1984) chose velocities of 2.0 km/s and greater to be indicative of such subsea permafrost, as compared with 1.5 km/s for sea water. They found such strata as far as 60 km offshore from the barrier islands. Their Figure 1 is reproduced in this report as Figure 3.21. Additional information is presented in Morack and

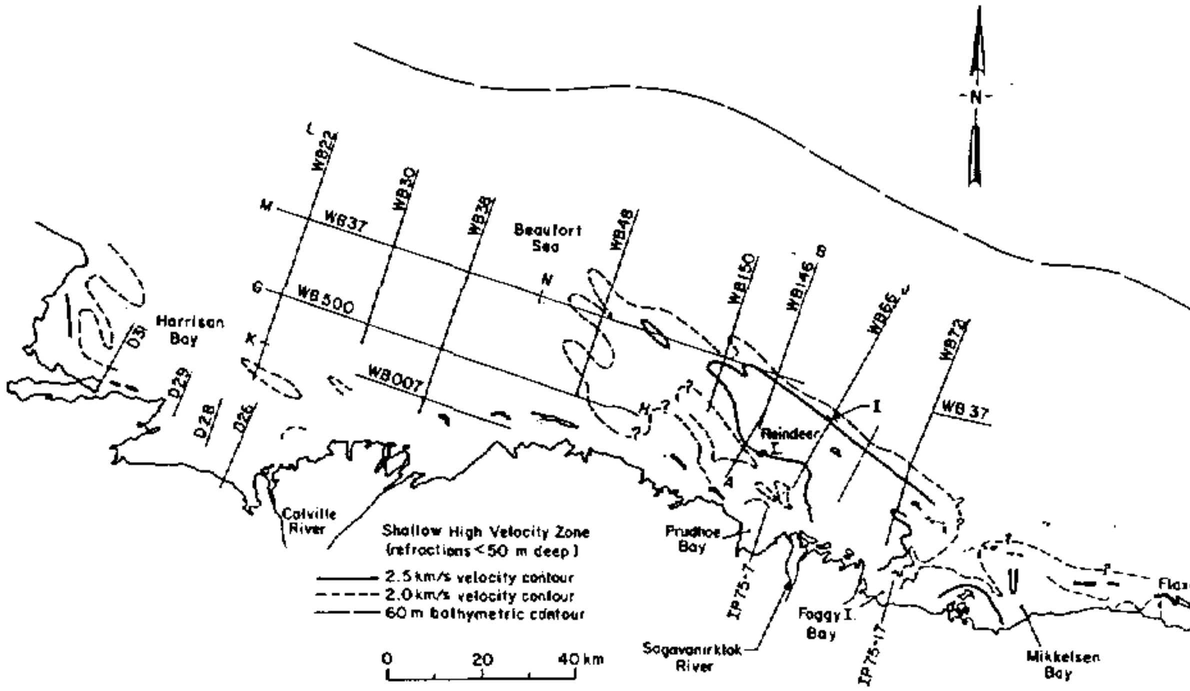


FIGURE 3.21. Distribution of known shallow high-velocity bottom material in the Beaufort Sea between Harrison Bay and Flaxman Island (from Neave and Sellman 1984).

Rogers (1984), and a more recent reference is Meyer (1996).

Summary.—Examination of the pulse levels and pulse spectra has quantified the importance of water depth in determining the frequencies that propagate to horizontal ranges that are many times the water depth. The observed behavior is consistent with a fairly simple representation of the propagation, given by the behavior of a single acoustic mode as shown in Equation 1 above. Using this equation, the attenuation of the single mode was estimated from data for the full 11-gun array as measured on 15 August 1996. With these data and the model, the source level at 1 m was estimated and compared to a theoretical calculation: the levels differed by only 1 dB, providing additional confidence in the use of the single-mode model as a representation of transmission loss over distances up to 2 km or perhaps slightly more.

The single-mode model and the attenuation rate deduced from measurements in shallow water (11 m) were used to estimate the expected received levels in deeper water (20 m) at ranges of 9-12 km. These model estimates were significantly higher than the measured levels, suggesting that the effective attenuation changed going into the deeper water. Thus, the single-mode model is not adequate for summarizing longer-range transmission. An alternative approach for the longer ranges is shown in a later subsection ("Long-Range Received Levels").

Direct examination of the single airgun data showed that the rate at which the levels decreased with range was a strong function of water depth. This implies that avoidance ranges for marine mammals probably vary with water depth, and that safety (shutdown) radii logically should be adjusted based on water depth.

Source Levels and Ranges for Specified Levels

Array Source Levels.—Effective horizontal source levels were estimated for bow and stern aspects based on short-range received level data recorded as the operating 11-airgun array was towed past *La Brisa* on 15 August (water depth 9-10 m). For the bow aspect, five measurements were taken from just before CPA, ranges 129-283 m, and a regression was computed with -10*log(R) (cylindrical spreading) forced:

RL (dB re 1 µPa) = 212.5 - 10*log(R) + 0.0026*R, (R in m)

The positive sign on the range coefficient is physically unrealistic but has a negligible effect for small values of R. The assumption of cylindrical spreading was based on the analyses described in previous subsections. From this equation, the level expected at distance 1 m if the array were a point source (the source level) is 213 dB re 1 µPa-m on an rms pressure level basis.

For the stern aspect, six measurements were taken just after CPA, ranges 150-321 m, and the regression line equation was

RL (dB re 1 µPa) = 222.4 - 10*log(R) - 0.03*R, (R in m)

From this equation, the source level is found to be 222 dB re 1 µPa-m on an rms basis.

Single Airgun Source Levels.—Using data and regression equations graphed in Figure 3.13, the difference in stern aspect received levels between the full 11-airgun array and the single airgun was found to be 23 dB. This 23 dB difference compares well with a predicted 20*log(11/1) = 21 dB difference assuming coherent addition of the 11 airgun pulses. Subtracting that 23 dB value from the 222 dB source level for the full array, the source level for a single 120 in^3 airgun was estimated to be 199 dB re 1 µPa-m on an rms basis. However, the short range single airgun measurements themselves do not predict an rms source level as high as 199 dB; a level closer to 192 dB re 1 µPa-m would be expected.

Peak Source Pressures.—The estimated effective source level of the full 11-airgun array is estimated above to be an rms pulse level of 222 dB re 1 µPa-m for propagation behind the vessel, and 213 dB re 1 µPa-m for propagation ahead of the source vessel. At the 6 closest measurement distances within 200 m, the peak pressures were about 8 dB higher than the rms pressures (e.g., Fig. 3.3). If this difference also applies at the source, then the source levels on a peak pressure basis would be 230 dB re 1 µPa-m for stern aspect and 221 dB re 1 µPa-m for bow aspect. In the units used by the geophysical industry (bar-meters, peak-to-peak), these peak pressures are approximately equivalent to 6.3 and 2.2 bar-meters. Levels expressed in bar-meters, peak to peak (P_a), can be converted approximately to peak levels in dB re 1 µPa with the following formula:

$$L_s \text{ (dB re 1 µPa-m)} = 20 \log (P_a) + 214$$

The equation is an approximation because it assumes that the positive and negative peaks in the pulse are of the same magnitude. In fact they are generally not the same, differing perhaps by as much as 50% and thereby leading to a possible error as large as 2.5 dB.

The above figures represent the effective source levels for long-distance horizontal propagation of sound from the full 11-gun array as used in the 1996 Northstar project, with airguns at depth 3½-4 m. As such, these figures can be expected to differ from the nominal source levels for downward propagation. When the application for an IHA (Incidental Harassment Authorization) for this project was submitted to the National Marine Fisheries Service, the source level for downward propagation was anticipated not to exceed 57.1 bar-meters peak-to-peak. This is approximately equivalent to a peak level of 249 dB re 1 µPa-m or an rms level of 241 dB. Thus, the measured effective source level for horizontal propagation was substantially less than the design limit for the nominal vertical source level. The difference was about 19 dB for stern aspect and 28 dB for bow aspect. After the IHA Application was submitted, Painter (1996) predicted a nominal vertical source level of 26.4 bar-m for the specific 11-airgun array to be used at Northstar, operating at depth 4 m. This is approximately equivalent to a peak level of 242 dB re 1 µPa, or 12 dB more than the "measured" peak source level for horizontal propagation of 230 dB at stern aspect.

Radii for Received Levels 200, 190, 180 and 160 dB.—The distances at which sounds from the full 11-airgun array diminish to 190, 180 and 160 dB re 1 µPa are of interest. The IHA issued to BPXA for this project required that airgun operations be temporarily suspended if seals were seen within the 190 dB radius, or if whales were seen within the 180 dB radius. Also, the IHA specified that the numbers of whales occurring within the 160 dB radius were to be estimated, on the assumption that they might have been disturbed by seismic pulses.

Prior to the field season, the 190, 180 and 160 dB radii were predicted to be 100 m, 650 m and 5 km, respectively. To be conservative, BPXA proposed to use a 150 m rather than 100 m shutdown radius for seals, and this proposal was adopted in the IHA. Based on preliminary analysis during August 1996 of some of the data quoted above, the estimated 190 dB and 180 dB radii were changed to 250 m and 750 m, and the shutdown distances were increased accordingly. Further analysis of the 1996 field measurements now allows a more definitive analysis. The 200 dB radius is also estimated for comparison.

The strongest source levels were found at stern aspect, i.e. behind the seismic source vessel: 222 dB re 1 µPa-m for stern aspect vs. 214 dB for bow aspect. These are the effective rms source levels for horizontal propagation. Also, the received levels were generally higher at any given distance at stern aspect than at bow aspect. In summary, for the stern aspect, the following radii were found for a time when sound propagated comparatively well:

RL (dB re 1 µPa)	Distance (m)
200	44
190	257
180	1020
160	4900

These values allow for variability and are thought to be the approximate maximum distances at which the specified rms sound levels might be received. If the regression equation for the stern aspect in Figure 3.10 is used to estimate typical radii, the results are

RL (dB re 1 µPa)	Distance (m)
200	31
190	240
180	960
160	3600

The measurements from which these estimates were derived were made with the receiving hydrophone at depth 8 m in water 9 m deep on 15 August 1996. The airgun array depth was 3½-4 m and the water depth at the source was 9-11 m (Fig. 3.10B). The measured received levels varied considerably from pulse to pulse and the tabulated received level vs. range tables were derived using curve-fitting to smooth the data.

Other sets of measurements obtained during full-array operations at Northstar gave distances significantly less than those tabulated above. The average distance for a received level of 160 dB re 1 µPa was approximately 3.7 km. This average comes from bow, beam and stern aspect data and includes measurements made with the full array on both the 15th and 16th of August.

Discussion.—The assumption that cylindrical spreading was occurring from the source to the short-range measurement locations is justified by the evidence for normal mode sound propagation previously presented. It is recognized that the source level estimates are strongly dependent on this assumption, and would be higher if propagation losses were higher than -10*log(R) along part of the propagation path. The calculated source levels are most useful as indicators of the relative levels of different sources operating in the same region, e.g. full 11-gun array vs. single airgun.

Long-Range Received Levels

Measurements of the survey pulses from the full array at ranges greater than 7 km were made in four ways: (1) by taking the receiving hydrophones on *La Brisa* to recording positions farther offshore than the source vessel either within the survey area or in the ice pack NNE of the survey area, roughly perpendicular to the coastline (030° T); (2) by taking the receiving hydrophones on *La Brisa* to recording positions WNW of the survey area, or roughly parallel to the coastline (300° T); (3) by dropping sonobuoys at greater ranges alongshore and offshore; and (4) by analyzing the sounds received and stored by the bottom recorder placed offshore from Northstar and, much farther east, offshore from Narwhal Island. These measurements aid in determining the long-range acoustic transmission loss for the relevant coastal areas of the Beaufort Sea (Fig. 3.22).

Boat-based Measurements Farther Offshore.—Measurements were made at ranges 1.0 to 2.1 km from *La Brisa* anchored in the survey area at 10:33-10:40 ADT on 15 August. Measurements at longer distances to the NNE (roughly perpendicular to the coast) were made on 15 August, 20:14-21:16 ADT (Fig. 3.22, circles). The *Point Barrow* presented a stern aspect during these recordings, including recording segments at ranges 9.4-9.9 km and 11.7-12.9 km. The water depths at the receiver varied from 23 m at the most distant (offshore) location to 9.4 m at the closest. The depths at the source were 11.7 to 13.6 m when the receiver was farthest away and 10.4-10.9 m when the receiver was closest.

Boat-based Measurements Alongshore.—Measurements at ranges 1.5 to 14.8 km to the WNW (roughly parallel to the coast) were made on 16 August, 09:34-11:47 ADT (Fig. 3.22, squares). The water depth at the receivers varied from 19 m at the most distant location to 15 m at the closer positions. The depths at the source varied from 6 to 14 m, but were mainly 13-14 m.

Sonobuoy Measurements.—Received levels were recorded from sonobuoys on 10 and 15 September (Fig. 3.22, diamonds). The levels plotted for distances 30 km and 41 km were recorded on 15 September when the airgun array was being operated with five airguns ("partial array"). For coherent combination of the sounds from the individual airguns, an increase from 5 to 11 airguns would be expected to increase the radiated sound by 20*log (11/5) or 7 dB (see §3.3). Therefore, in Figure 3.22, the measured received levels for 15 September were increased by 7 dB to approximate the levels that would have been received if a full 11-gun array had been in use.

Bottom-Recorder Measurements.—Received levels were recorded at the bottom recorders continuously beginning at midnight on 31 August. Airgun sounds were recorded frequently at the Northstar recorder but only twice at the Narwhal Island recorder. On 13 September the seismic vessel was operating in the patch labelled "E" on Figure 3.1. The water depths at the source varied from 12 to 20 m (according to fathometer records from the source boat) during the period of operation analyzed. Virtually all pulses from one seismic line were received at the Northstar bottom recorder, but only a few were recognized at the Narwhal Island bottom recorder 67 km away. The received rms pulse levels there were on

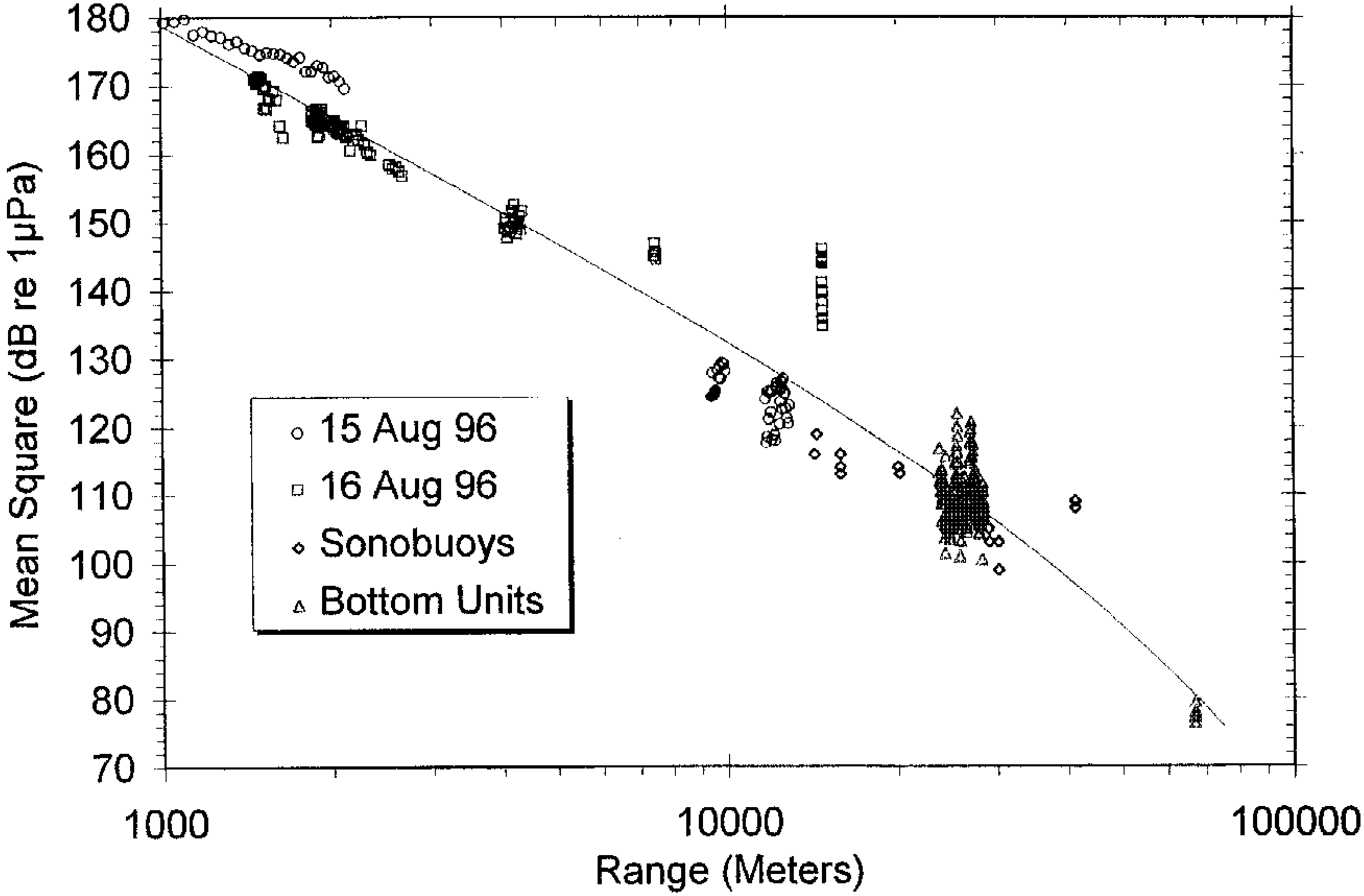


FIGURE 3.22. Summary of rms pulse levels vs. distance for distances >1 km, 15 Aug.-13 Sep. 1996. The line represents a least squares fit to all 372 data points:

RL = 179.1 - 43.95*log(R) - 0.28*R

for range R in kilometers and received level RL in dB re 1 µPa.

the order of 77 dB re 1 µPa (Fig. 3.22, triangles), compared to a minimum broadband background level of 75 dB observed at that site during 14 days of operation. The pulse frequencies (not shown) were observed to extend from about 200 to 400 Hz, signifying that most of the pulse energy had been stripped away by the shallow water propagation.

Listening to the airgun pulses received at the Northstar bottom unit provided a clear illustration of the effects of water depth at the source on the qualities of the received signal. The receiver depth was constant, of course, at 23 m (two meters above the bottom). The survey lines were along 030°-210° true course lines, roughly away from and back toward the Alaskan coast (see Fig. 2.1, 2.4 in Chapter 2). Depths at the source varied from as little as 5 m at the southern ends of the lines to 12 m or more at the north ends of each line. Listening at eight times real-time speed, the listeners could hear a 45-minute traverse along one source line in less than 6 min; the speed-up made the frequency and level changes easy to recognize as the source vessel moved from shallow to deep water (or the reverse).

Qualitatively, the listeners heard the sounds increase in level and decrease in pitch (frequency) as the airguns moved along the 030° course, from shallow into deeper water. That is, the sounds grew stronger and lower in tone. Then, as the airguns moved along the reciprocal course (210°) into shallower water, the received level decreased and the pitch increased. That is, the sounds grew weaker and higher in tone. Often the level decreased to less than the ambient noise and the airguns could not be heard. The shallowest water does not support low frequency sound transmission, so only the highest frequencies are heard when the source is in the shallowest water. Some of the reduction in received level when the source moved into shallow water was due to the slightly longer distance from the source to the Northstar recorder. However, because the source generates most of its energy at low frequencies, below 150 Hz, most of the level reduction when the source was near the southern (shallow) ends of the source lines resulted from the shallow water stripping away the low frequency components.

Summary.—All of the long-range data on received rms pulse levels are plotted together vs. distance from the source in Figure 3.22. As noted above, the levels received via sonobuoy on 15 September have been increased by 7 dB to adjust for the fact that the source array was being operated with only five airguns. The considerable variability observed is not surprising, given the influences of water depth and bottom characteristics and the variety of locations from which these data come. The levels summarized in Figure 3.22 represent the total sound level at all frequencies making up the received pulse.

A least squares fit of a simple equation to all 372 data points resulted in the following:

RL (dB re 1 µPa) = 179.1 - 43.95*log(R) - 0.28*R (R in km).

The standard error of the fit was 8.8 dB; the coefficient of determination was 0.829. The equation estimates the received sound levels that might be expected at long ranges from the full array at stern aspect while it is operating in the Northstar area. In this case, no cylindrical spreading term was forced. As discussed earlier in this section, the single mode model (for which a cylindrical spreading term is appropriate) did not fit the long range data.

Based on the fitted curve in Figure 3.22, the received levels, on an rms pressure basis, are expected to be 160 dB re 1 μPa at distance 2.6 km from the source, 132 dB re 1 μPa at 10 km, 116 dB at 20 km, 106 dB at 30 km, and 97 dB at 40 km. Variability around these values may be ±10 dB or more, especially at distances greater than 5 km. To estimate received levels at long ranges from the Northstar survey area in a more precise manner, it would be necessary to develop a more complex model taking account of additional parameters.

3.5 Boat Sounds

Measurements

The radiated sounds of four primary boats used in the seismic survey were measured. The propulsion and other characteristics of these boats are described in Chapter 2 (§2.2). Measurements were made with the ITC 6050C hydrophone suspended from the sparbuoy deployed near *La Brisa*. Hydrophone depth was 9 m or, in shallower water, 1 m above the bottom. *Pt. Barrow*, the Crowley Marine tugboat used to tow the airgun array, was measured on 17 August at speed 5.6 knots with *La Brisa* anchored in water 5.3 m deep and the hydrophone at a depth of 4.3 m. *Peregrine Falcon*, used primarily for deploying and retrieving battery boxes, was measured on 13 August at speed 8.3 knots in water 11.7 m deep. *Sag River*, another Crowley tugboat used to push Barge 216 for ocean bottom cable deployment and retrieval, was measured on 19 August at speed 4.5 knots inbound and speed 5.8 knots outbound in water 10.7 m deep. *Faraday*, an LCM-type of boat used early in the season as a supplementary cable handling vessel, was measured on 14 August at a speed of 7.7 knots in water 11.7 m deep.

The received levels at various distances from each boat are shown in Figure 3.23 by ⅓-octave band and (at the right sides of the graphs) for three broader bands: 20-1000, 20-2000 and 20-5000 Hz. In general, the received levels increased as the boats approached and diminished as the boats moved away. However, there were some minor exceptions. This is to be expected given ▸ the usual variability in the sounds from a moving vessel and ▸ the complexities of sound propagation in shallow water. (Even with a steady source level, received level would not diminish smoothly with increasing range.)

The appearance of a bowl-shaped curve in the ⅓-octave data at the lowest frequencies is associated with the very shallow water of the measurements. As described in the previous section, low-frequency cutoff occurs at a frequency related to the water depth and to the density and speed of sound in the bottom. This cutoff frequency increases as water depth decreases. The received level curves for *Pt. Barrow* show the highest cutoff frequency (at about 100 Hz) and the most dramatic fall-off in level with increasing distance—as expected for the measurement location with the shallowest water, 5.3 m.

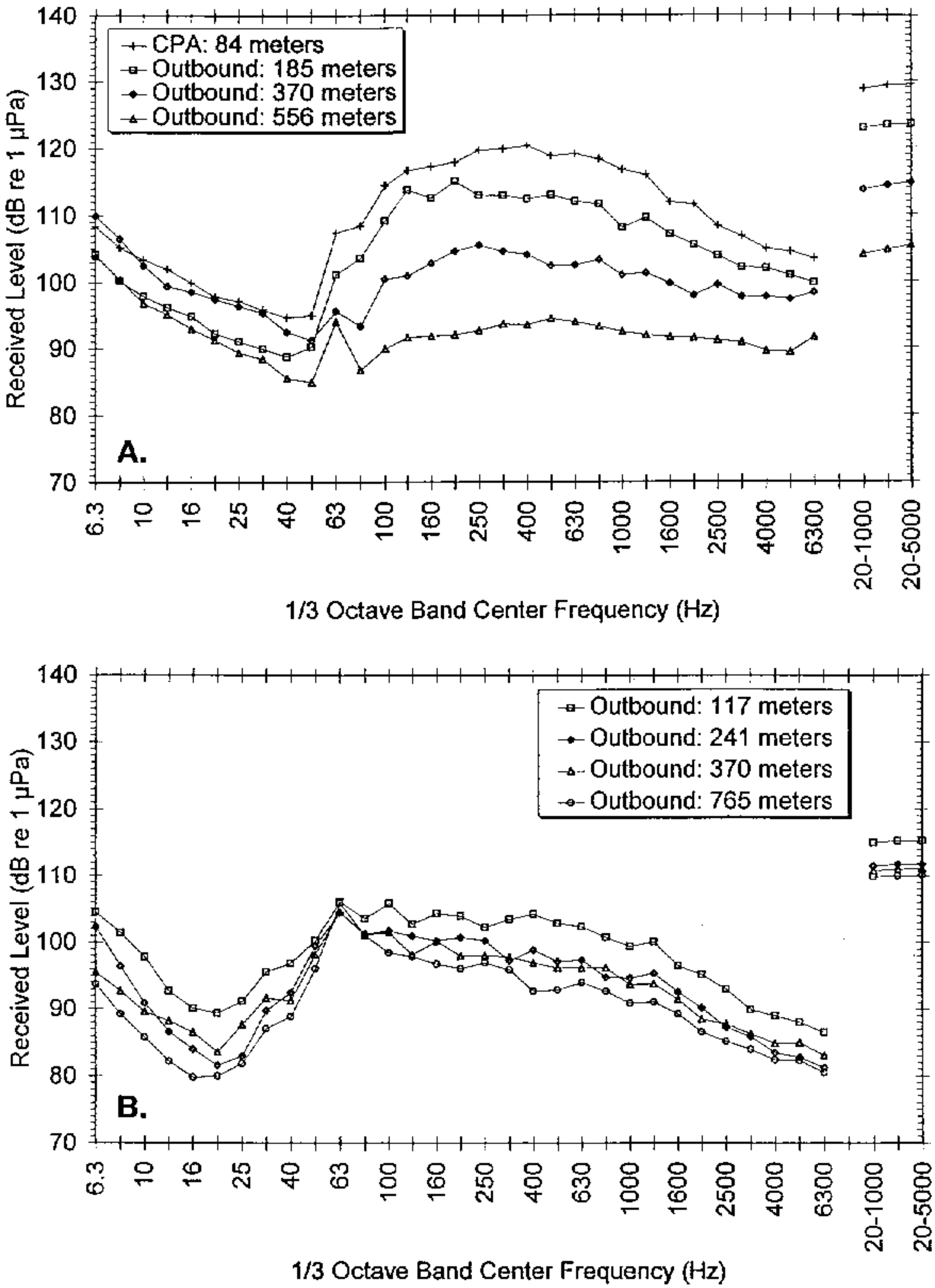
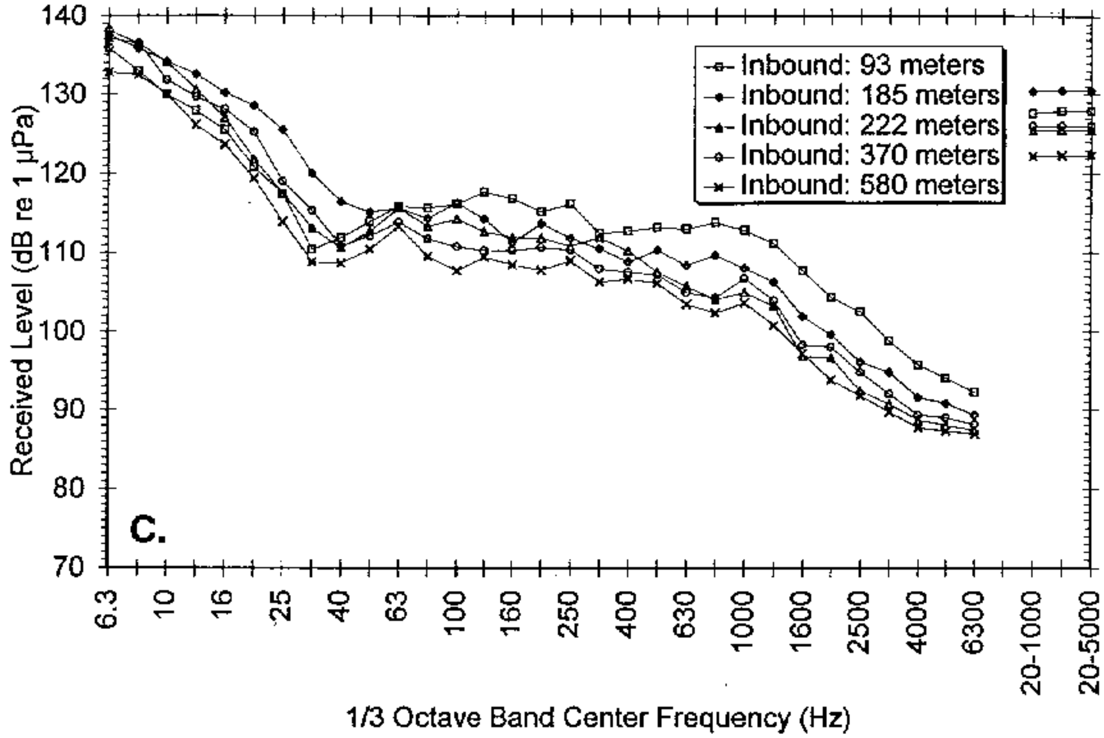


FIGURE 3.23. Boat noise at various ranges: radiated noise measurements in ⅓-octave bands for several vessels at various ranges from the receiver. *(A)* is *Pt. Barrow* outbound at 5.6 knots, water depth 5.3 m; *(B)* is *Peregrine Falcon* at 8.3 knots outbound, water depth 11.7 m; *(C)* is *Sag River* with *Barge 216* inbound at 4.5 knots, water depth 10.7 m; *(D)* is *Sag River* with *Barge 216* outbound at 5.8 knots; *(E)* is *Faraday* outbound at 7.7 knots, water depth 11.7 m. Levels at low frequencies show the effects of normal mode sound propagation in very shallow water.



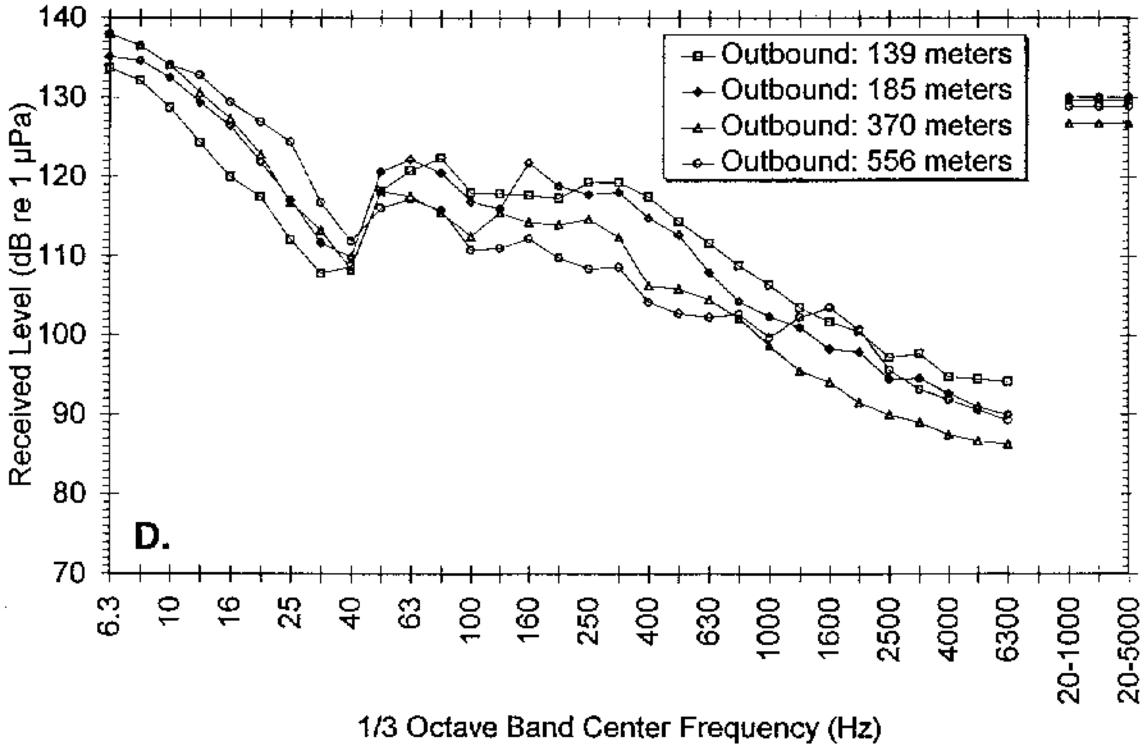


FIGURE 3.23. Continued.

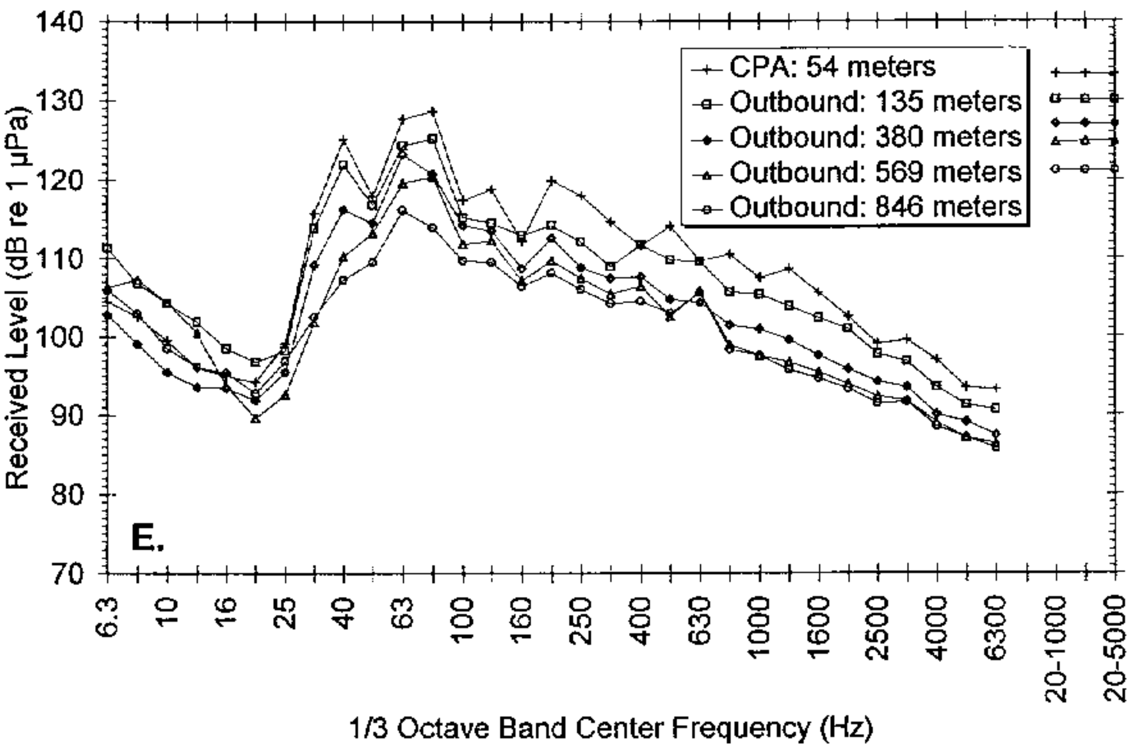


FIGURE 3.23. Continued.

Boat Source Levels

Figure 3.24 shows estimates of the effective source levels of these four boats in the ⅓-octave bands above the cutoff frequency. For *Sag River*, the data from the outbound run at 5.8 knots were used. Because of the modal sound propagation manifest in these shallow waters, the best range correction method is cylindrical spreading from CPA to one meter. Every mode propagates with cylindrical spreading.

The boat that emitted the strongest sounds overall (by 2 dB) was the *Sag River* pushing Barge 216 at 5.8 knots outbound; its estimated broadband source level (100-1000 Hz band) was 150 dB re 1 µPa-m. This result is not surprising considering that the *Sag River*'s three propellers are not shrouded. In contrast, the propellers on the *Pt. Barrow*, a more powerful vessel (2100 hp vs. 1095 hp) were in Kort nozzles. Nozzles are known to reduce the radiated underwater noise (Greene 1987; Richardson et al. 1995:114). Also, the *Sag River* was traveling slightly faster when measured. The source level of the *Pt. Barrow* was the second strongest, with an estimated source level of 148 dB re 1 µPa-m in the 100-1000 Hz band. The *Faraday* ranked third, with broadband source level 143 dB, and the *Peregrine* was "quietest", with broadband source level 139 dB. Vessels propelled by water jets, as used on *Peregrine* and *La Brisa*, may be inherently quieter than those with propellers.

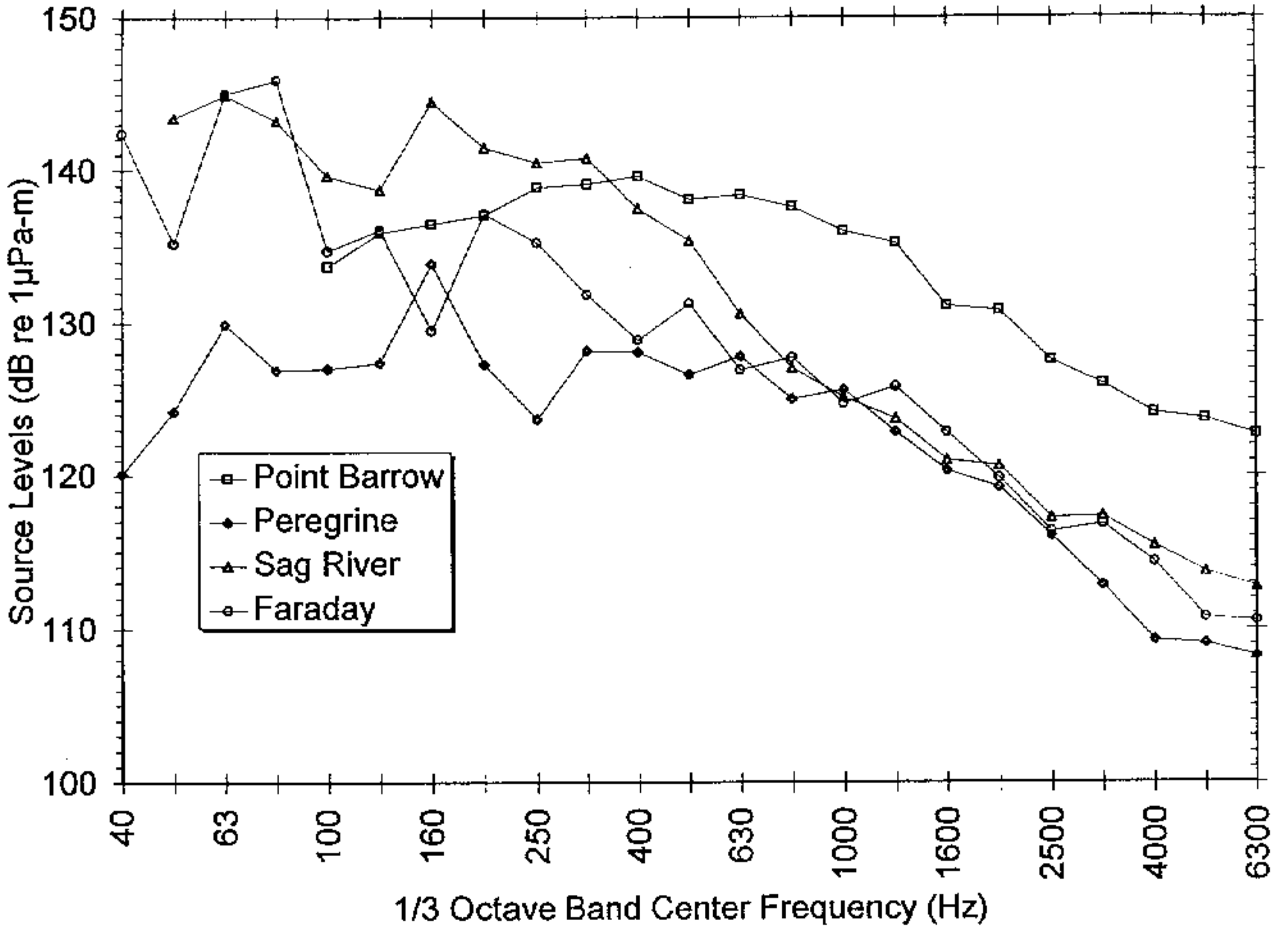


FIGURE 3.24. Source levels of boat noise: estimated effective source levels in ⅓-octave bands for the four boats whose measured sound levels are shown in Figure 3.23. For *Sag River*, the "5.8 knots outbound" condition was used (*cf.* Fig. 3.23D).

All quoted source levels are for the 100-1000 Hz band. Inclusion of the lower frequency bands would raise the overall source level of each boat. Boats such as these often emit strong sounds at low frequencies. However, judging from the ⅓-octave levels graphed in Richardson et al. (1995:112) for various boats, the 100-1000 Hz ⅓-octave source levels estimated for boats used at Northstar are consistent with previous estimates for similar-sized vessels.

Discussion

The estimates in Figure 3.24 are most useful in comparing the relative source levels of the various boats rather than their absolute source levels. The latter depend strongly on the accuracy of the assumed propagation loss between the source and the closest measurement distance. Also, *Pt. Barrow* was measured in such shallow water that reliable source level estimates were not feasible at frequencies below about 100 Hz. Therefore, the sounds of all four boats measured are compared based on the broadband sum of the 100-1000 Hz ⅓-octave band levels.

3.6 Aircraft Sounds

Sound transmission from air to water is restricted to a cone 26° wide under calm conditions. Sound outside the cone is totally reflected by the water surface (Richardson et al. 1995:80*ff*). Coupling is effective to somewhat wider angles if there are waves because they change the angle of the surface. However, the general effect of this restriction is to limit the duration of detectable sound at an underwater receiver from a passing airborne source.

The aircraft used during the whale surveys was N7UP, a modified Commander 680FL. It had been retrofitted with 400 hp Avco Lycoming IO-720 engines providing a total of 800 hp. The propellers had three blades. Normal speed during transect surveys and during measurements of aircraft sounds was 220 km/h (120 knots).

The sounds from the aircraft were recorded by means of a sequence of straight-line flights at altitudes 150 m, 310 m, 460 m and 760 m (500-2500 ft) over a sonobuoy. There were three flyovers at 460 m and two at each of the other altitudes. The sonobuoy was at 70°44'N, 149°10'W, in water about 20 m deep, and its hydrophone was suspended at 10 m. Beaufort Wind Force at the recording location was 0 (i.e. sea state 0), and ice cover was estimated to be 30%.

Propeller blade rate tones dominated the spectrum at all altitudes. The fundamental frequency was from 106 to 112 Hz. This range corresponds to a propeller shaft rate of 2120-2240 rpm and, with 3-bladed propellers, to a blade rate of 6360-6720/min (106-112/s). Some of the variation was presumably related to doppler shifts as the aircraft flew overhead. Numerous higher harmonics of the fundamental frequency also were evident in the spectrum (e.g., Fig. 3.25).

For three flyovers at altitude 1500 ft (460 m), the overall 20-1000 Hz band levels received at 10 m depth were 111, 103 and 115 dB re 1 μPa. These values are based on a 3.5 s averaging time. Sound levels received underwater increase and decrease rapidly as an aircraft flies overhead, particularly at the lowest altitudes. Thus, the received levels could be slightly higher with a shorter averaging time (especially for the lower-altitude passes), and would be lower if based on a longer averaging time. The spectrum for the pass when the 115 dB level was recorded is shown in Figure 3.25.

The ⅓-octave band levels and broadband (20-1000 Hz) levels of the sounds received during one flyover at each altitude are plotted in Figure 3.26. The data plotted for each altitude are those from the flyover that gave the strongest received sounds. In general, received sound levels diminished with increasing aircraft altitude, as expected. As expected from the narrowband spectrum (Fig. 3.25), ⅓-octave bands that contained one of the strong harmonic-

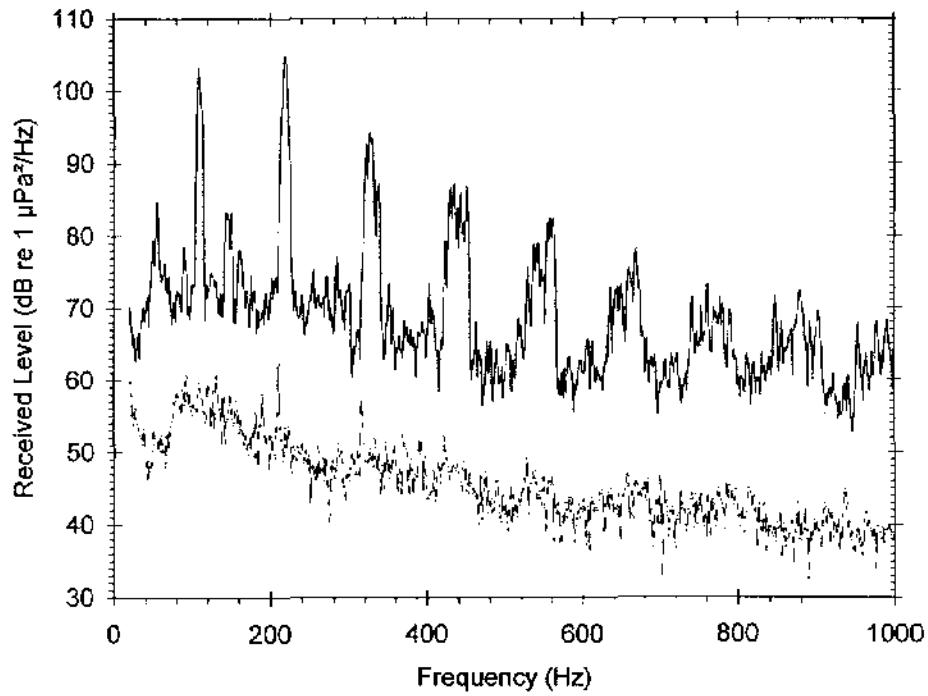


FIGURE 3.25. Underwater sound pressure spectral density for the whale survey aircraft, a modified Commander 680FL. Aircraft sound was recorded via a sonobuoy as the aircraft flew overhead at altitude 460 m (1500 ft) and speed 220 km/h (120 knots). Dashed (lower) curve is the ambient noise shortly before the aircraft flew overhead. Hydrophone depth was 10 m, spectrum analysis bandwidth was 1.7 Hz, and averaging time was 3.5 s.

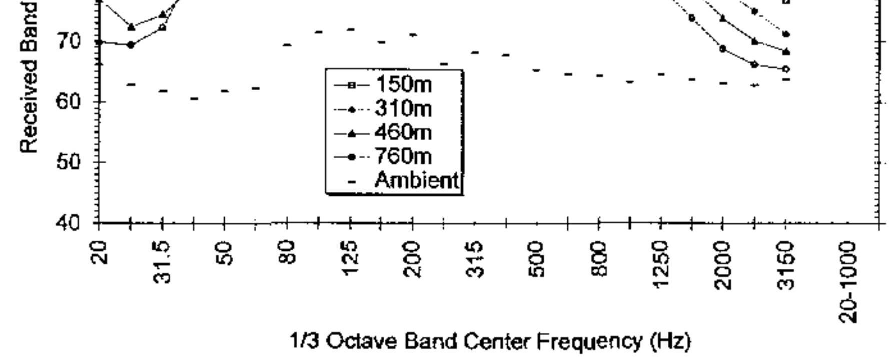


FIGURE 3.26. One-third octave band levels for modified Commander 680FL aircraft flying at altitudes 150, 310, 460 and 760 m over a sonobuoy with hydrophone depth 10 m. Averaging time was 3.5 s.

ally-related tones had higher levels than ⅓-octave bands not containing any of these tones.

As compared with the Twin Otter aircraft, which is also commonly used for surveys of marine mammals, the Commander 680 produced a tonal family with slightly higher fundamental frequency (~108 vs. ~83 Hz). For overflights at altitudes of 460 m and at normal aerial survey speeds, the received levels were several decibels higher for the Commander 680 than for Twin Otters on both an overall broadband basis and for the strongest tone (*cf.* Richardson et al. 1995:105*ff*; Patenaude et al. MS). Brewer et al. (1993) reported overflight sounds from the same aircraft. However, their sonobuoy hydrophone depth was 27 m, reducing the received levels compared to those at 10 m (this study) or at the 3-18 m depths where Twin Otter sounds have been measured in our previous studies. Comparisons among studies are also confounded by the different averaging times that have been used.

3.7 Ambient Noise

Ambient noise was measured underwater on an opportunistic basis with hydrophones and sonobuoys, and systematically via the two bottom recorders that were retrieved. From all four sources, ⅓-octave band levels were calculated from each observation to be included in statistical analyses. Wider band levels (20-1000 Hz) were also calculated to provide a single summary of the ambient noise at each measurement time.

Time Variation

Boat- and sonobuoy-based measurements of ambient noise were opportunistic, prohibiting a systematic examination of variability in ambient noise. The 20-1000 Hz band levels are plotted against time in Figure 3.27. This shows wide variation in the ambient noise levels, as would be expected with varying conditions of wind and waves. Times with noticeable man-made sounds such as airgun and boat sounds are excluded from these measurements.

The bottom recorders operated continuously. For one minute out of every 14 min 24 s (1/100th of the day), sampling occurred at 2000 times per second, twice the normal rate. This permitted an ambient noise spectrum including frequencies up to 1 kHz to be computed 100 times per day. The frequency resolution of these analyses was 1.7 s and the averaging time was 59.9 s. From these spectra the ⅓-octave and the 20-1000 Hz band levels were computed. Some of these observations will include bowhead calls, seismic pulses, and sounds from unknown sources because these results were computed for regular intervals (14 min 24 s) without editing. However, both the whale calls and the seismic pulses were brief and widely spaced. Also, the two bottom recorders were placed about 15 km and 48 km from the closest area where seismic exploration occurred during the recording period (Fig. 3.1). At the Narwhal Island recorder, seismic pulses were rarely detected and, even then, very weak.

Figure 3.28 shows the 20-1000 Hz band levels in relation to time for each of the two bottom units. It is evident that the ambient levels at a given site tended to wax and wane gradually over periods of hours or days. There were varying amounts of shorter-term fluctuation, including occasional high-level transient sounds for just a single sampling period. To

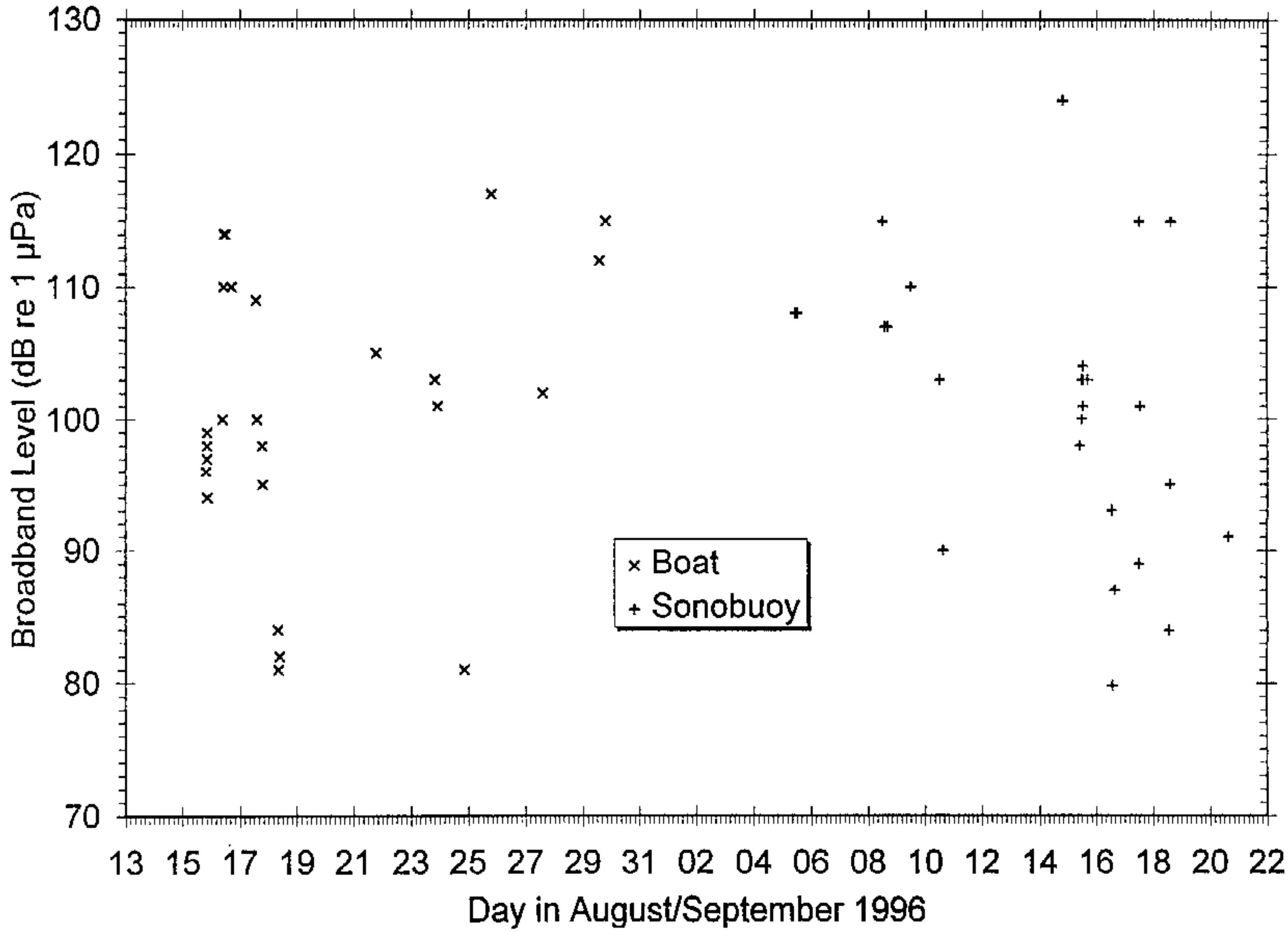


FIGURE 3.27. Hydrophone and sonobuoy measurements of broadband (20-1000 Hz) ambient noise levels, August-September 1996, central Alaskan Beaufort Sea. There were 25 boat-based samples and 27 sonobuoy samples of ambient noise.

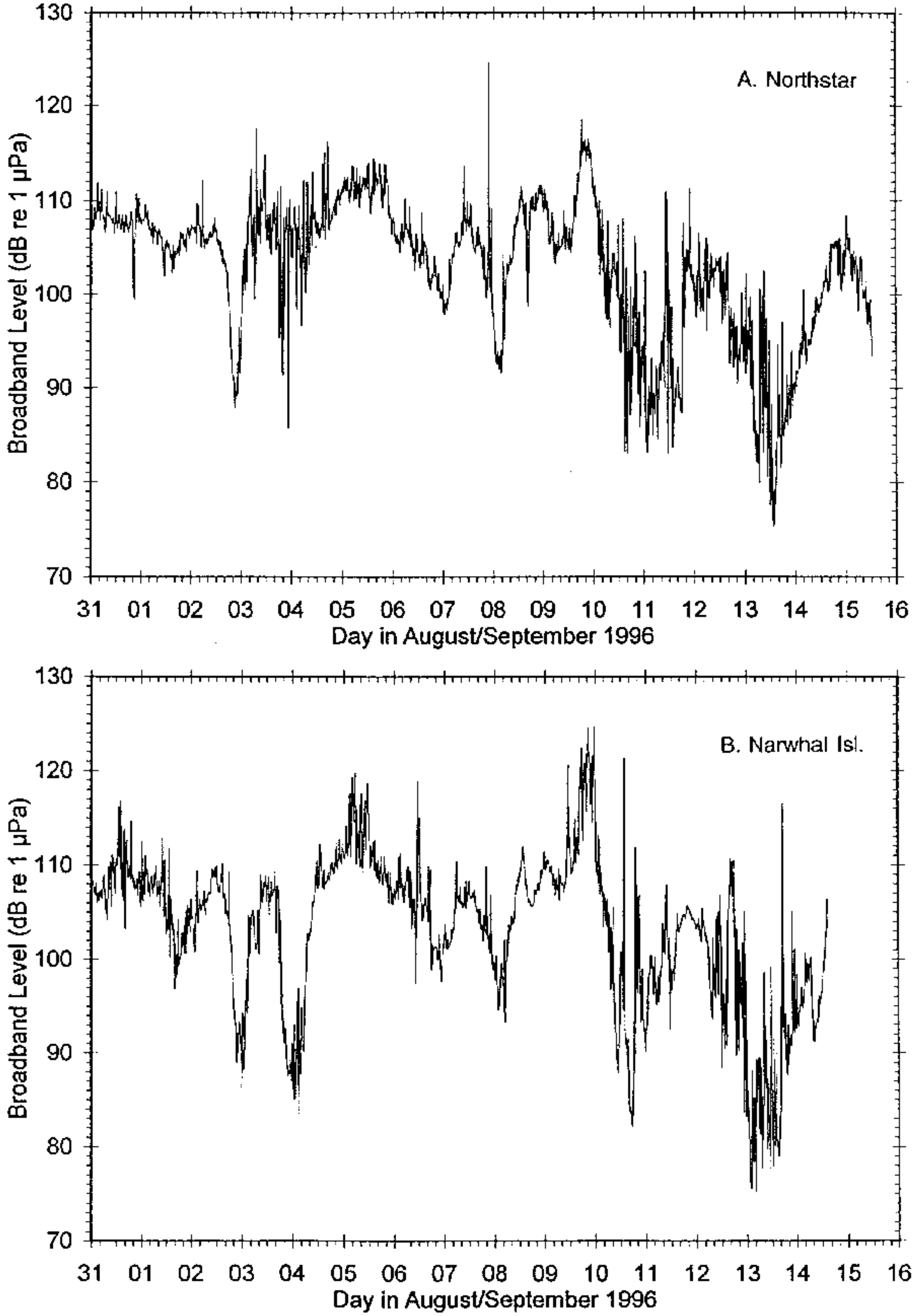


FIGURE 3.28. Bottom recorder measurements of broadband (20-1000 Hz) ambient noise levels, 31 Aug. to 14 or 15 Sep. 1996. *(A)* Northstar recorder. *(B)* Narwhal Island recorder. There are 100 measurements per day from each recorder.

the human listener, the sounds included occasional bumps, pops and even bangs of unknown origin.

Statistical Summary

Hydrophone Data.—There were 25 samples of ambient noise as measured with boat-based hydrophones. The resulting ⅓-octave band levels and 20-1000 Hz band levels were sorted to determine the percentile values for each band (Fig. 3.29). The median 20-1000 Hz band level was 100 dB re 1 μPa.

Sonobuoy Data.—There were 27 sonobuoy-based ambient noise analyses (Fig. 3.30). The median 20-1000 Hz band level was 103 dB re 1 μPa.

Bottom Recorder Data.—There were 100 ambient noise analyses per day for each bottom recorder. The Northstar unit collected 1552 samples while the Narwhal Island unit, which was retrieved one day earlier, collected 1460 samples (Fig. 3.31, 3.32). The respective median levels for the 20-1000 Hz band were 105 and 106 dB. The same data are presented on a narrowband (spectrum level) basis in Figures 3.33 and 3.34.

The most notable differences between the median spectra near Northstar and Narwhal Island were for frequencies below 30 Hz, where the Narwhal Island data showed higher apparent levels of ambient noise. This apparent difference may have been an artifact. Flow noise from water current around the hydrophone may have influenced the recorded sound below 30 Hz, especially off Narwhal Island. The median and 95^{th} percentile spectra from the two sites were otherwise in general agreement. However, the 5^{th} percentile spectrum levels differed markedly above 150 Hz. The 5^{th} percentile levels (but not other percentiles) recorded off Northstar were higher at these higher frequencies.

Discussion

Ambient noise was measured with boat-based hydrophones from 15 to 29 August. The sonobuoy-based measurements were from 5 to 20 September. The bottom units began recording at midnight on 31 August and were retrieved on 14 September off Narwhal Island and on 15 September off Northstar. The boat-based hydrophone data had the lowest median broadband (20-1000 Hz) level, 100 dB, of the four data sets. Boat-based measurement times were probably biased toward better weather (lower wind and waves) and therefore to lower ambient levels generally. The sonobuoy data provided a median broadband level of 103 dB, which was 2-3 dB less than the median levels at the bottom recorders. Sonobuoys were dropped in a wide variety of sea conditions, including Beaufort Wind Forces ranging from 0 to 5. Also, most sonobuoys were dropped at places farther from shore and with deeper water as compared with the locations of boat-based measurements. The bottom recorders also operated at locations deeper than the sites sampled by hydrophone. The bottom recorders operated continuously without regard to weather or ice conditions.

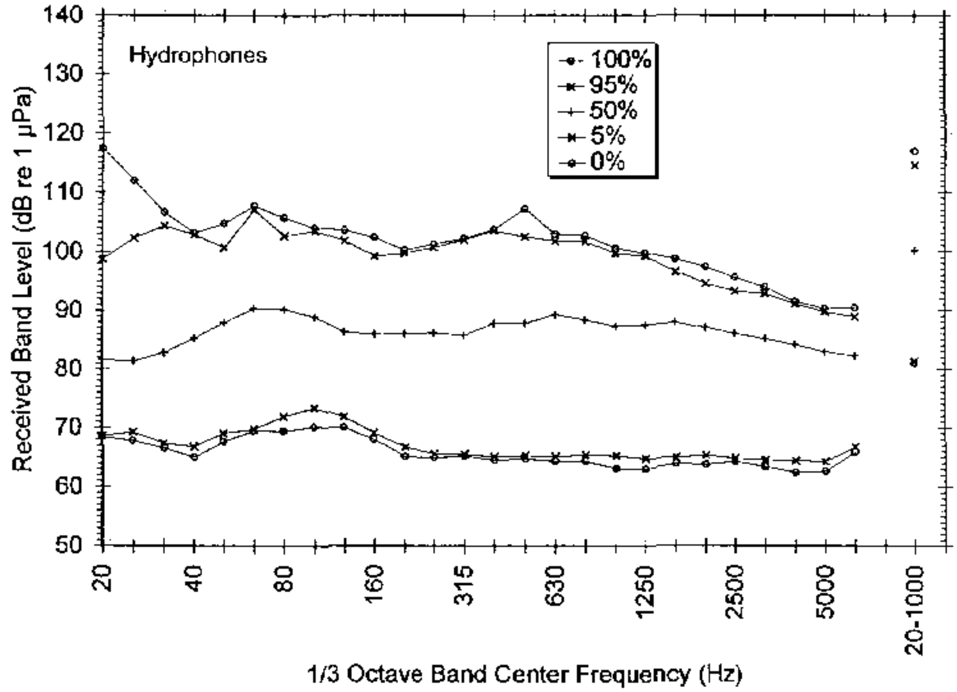


FIGURE 3.29. Percentile distribution of ambient noise measured by boat-based hydrophones, ⅓-octave bands (n=25 samples).

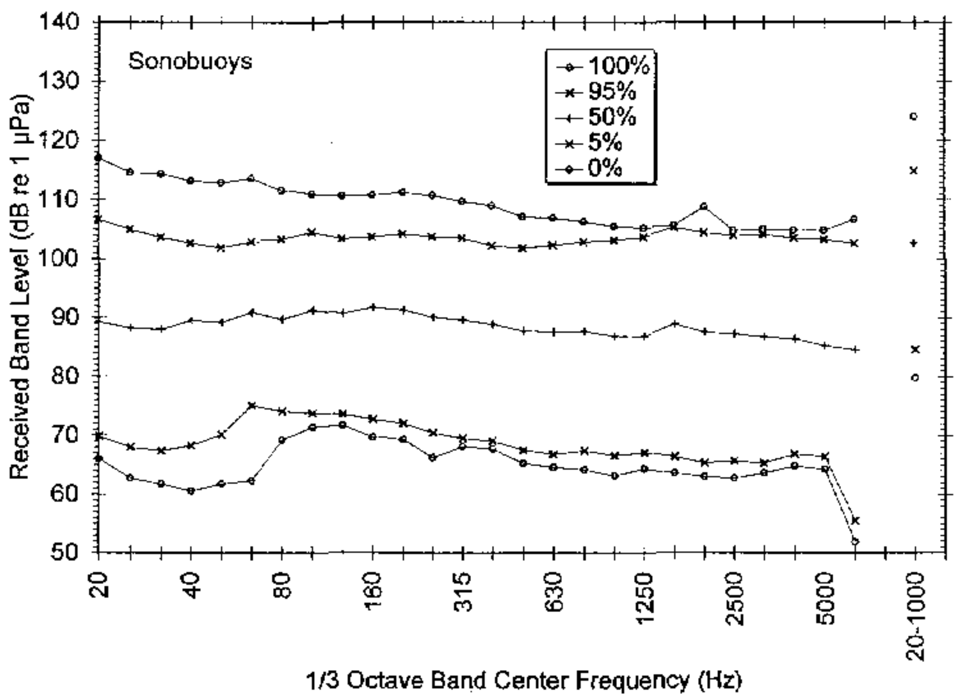


FIGURE 3.30. Percentile distribution of ambient noise measured by sonobuoys, ⅓-octave bands (n=27 samples).

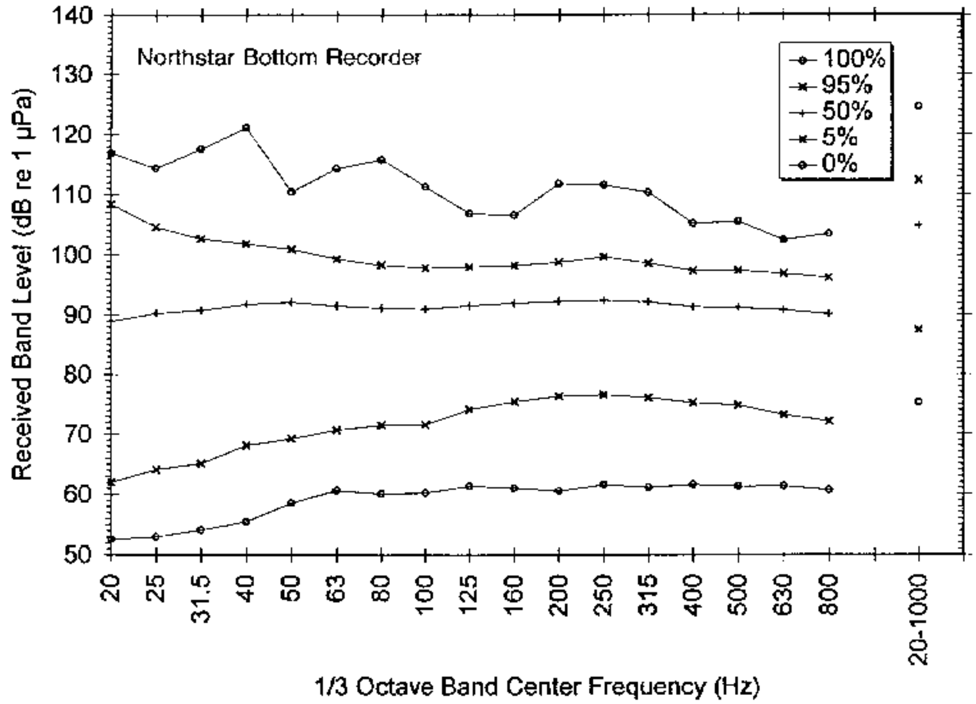


FIGURE 3.31. Percentile distribution of ambient noise measured by Northstar bottom recorder, ⅓-octave bands (n=1552 samples over 15.52 days).

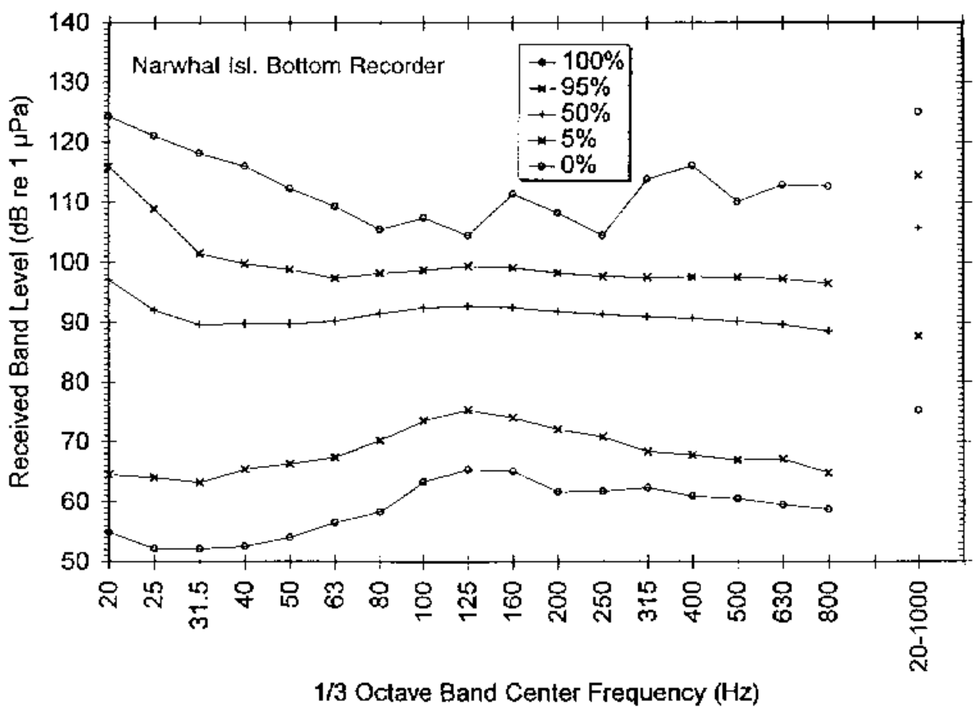


FIGURE 3.32. Percentile distribution of ambient noise measured by Narwhal Island bottom recorder, ⅓-octave bands (n=1460 samples over 14.60 days).

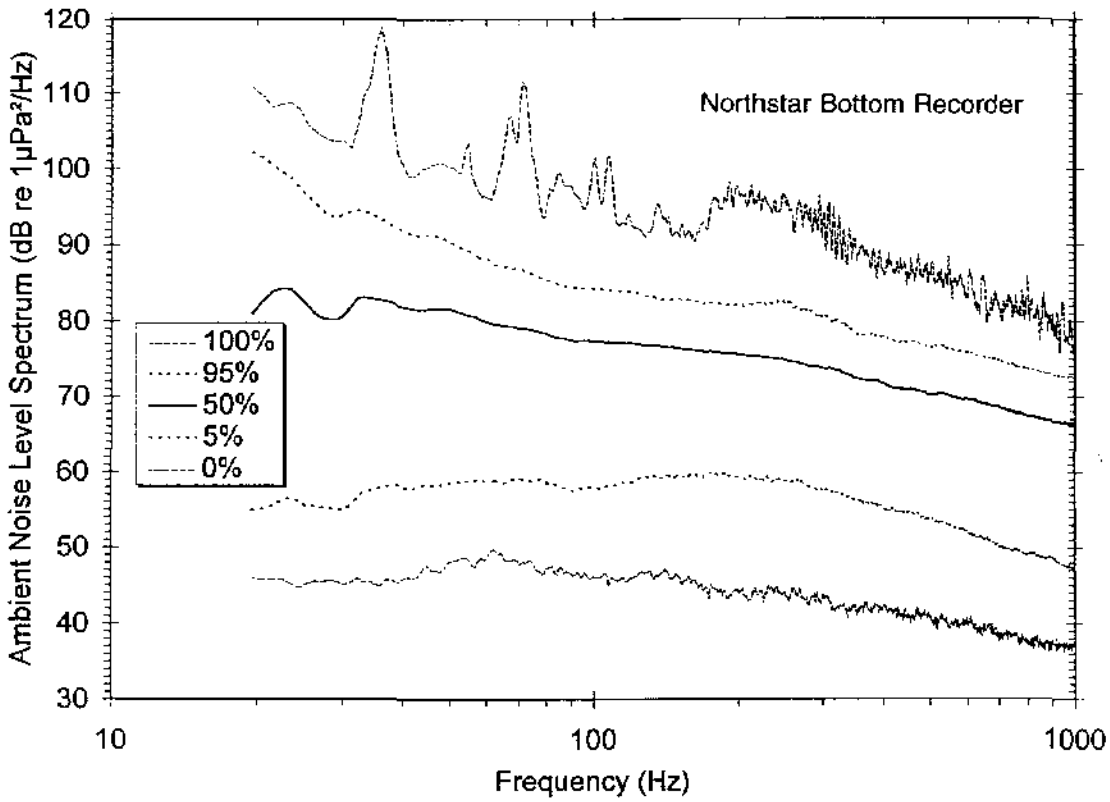


FIGURE 3.33. Percentile distribution of ambient noise spectrum levels measured by the Northstar bottom recorder. The analysis bandwidth was 1.7 Hz.

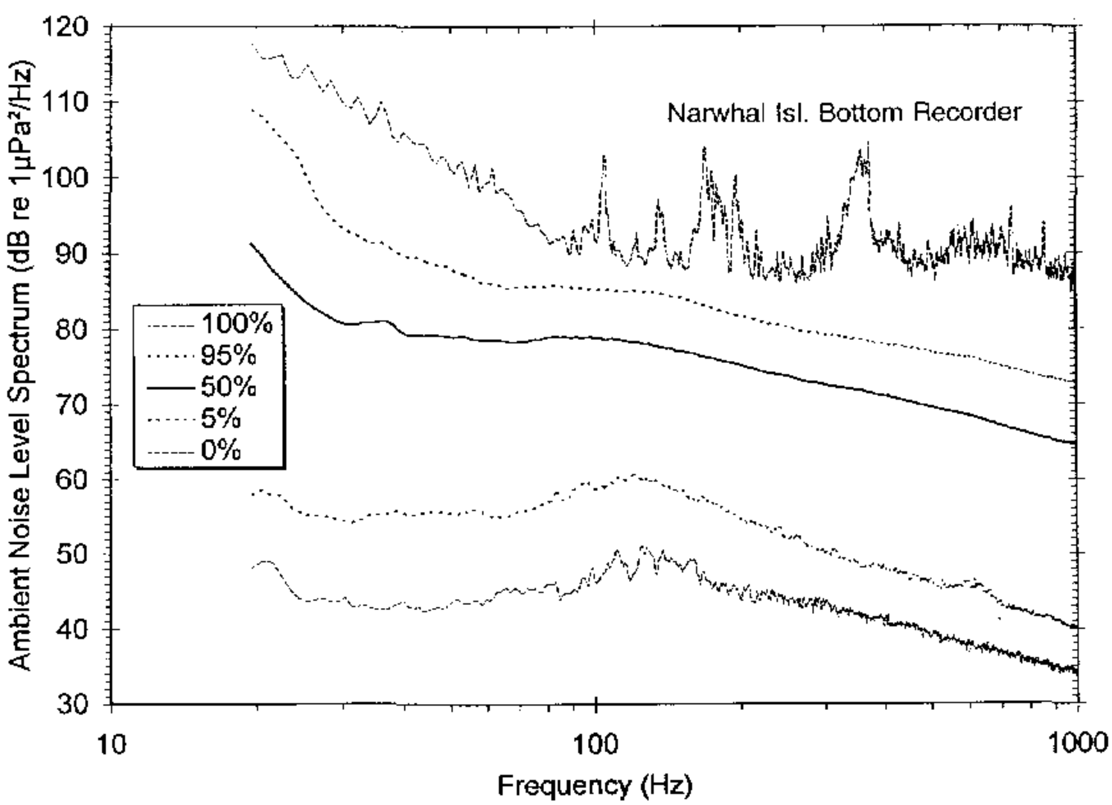


FIGURE 3.34. Percentile distribution of ambient noise spectrum levels measured by the Narwhal Island bottom recorder. The analysis bandwidth was 1.7 Hz.

How do these ambient noise measurements compare with others? A study of previous ambient noise measurements in the Northstar area was reported by Greene (1996). There were three sources of data: sonobuoys dropped on 24-30 August 1995, a bottom hydrophone cabled to Seal Island on 21-29 September 1984, and a hydrophone cabled to Sandpiper Island on 27 September-11 October 1985. Data from the two island hydrophones excluded times during drillrig operations on the respective artificial islands.

Ambient noise analyses from 40 segments of sonobuoy recordings offshore of Northstar from 24-30 August 1995 showed a median 20-1000 Hz band level of 95 dB re 1 μPa. The 1984 Seal Island hydrophone data also showed a median 20-1000 Hz band level of 95 dB, as did the 1985 Sandpiper Island hydrophone data. Thus, these earlier studies in the same general region revealed significantly lower median ambient noise levels than were observed in 1996 near Northstar.

The median levels documented with the bottom recorders were comparable to the wind and wave sounds expected from sea states 4-5 or Beaufort Wind Forces 5-6 (Wenz 1962). The presence of ice floes in the area most of the time generally prevented the build-up of large swells. However, smaller waves splashing against the floes may contribute considerable ambient noise.

Most of the energy in the seismic pulses, as received at long distances, was in the 50 to 400 Hz band. Therefore, the ambient noise in that band is relevant in determining how far away the seismic pulses would be detectable above natural background noise levels. The 5th, 50th and 95th percentile ambient noise levels in the 50-400 Hz band were 81, 101 and 108 dB re 1 μPa.

3.8 Whale Calls

Bowhead whale calls were recorded on the bottom recorders and noted during playback in the lab. Playback was usually at 8x actual speed. Call detection rates were calculated on a per hour basis for each recorder, and are graphed against time in Figures 3.35 and 3.36. The times when audible airgun pulses were received at each recorder are noted for reference.

The three bottom recorders that operated successfully during testing on 25-28 August 1996 provided useful data for about 80 hours. The positions are shown by in Figure 3.1 by ⊗ symbols. Figure 3.35 shows the 20-1000 Hz ambient noise levels, the number of bowhead calls detected per hour, and the presence of airgun sounds, plotted vs. time. It is noteworthy that bowhead calls were detected as early as 25 August, primarily at the northern and central locations (Fig. 3.35A,B vs. C). The total numbers of bowhead calls counted over the full deployment period were 930 at the southern unit, 1216 at the central unit, and 823 at the northern unit. This distribution of calls, although from only a limited time before the main migration is expected to begin, appears to support our selection of the central unit location at the core of the migration corridor. During this 3-day recording period, the airguns operated only on August 25th. Airgun sounds were received at the southern bottom recorder but not at either the center or the northern position.

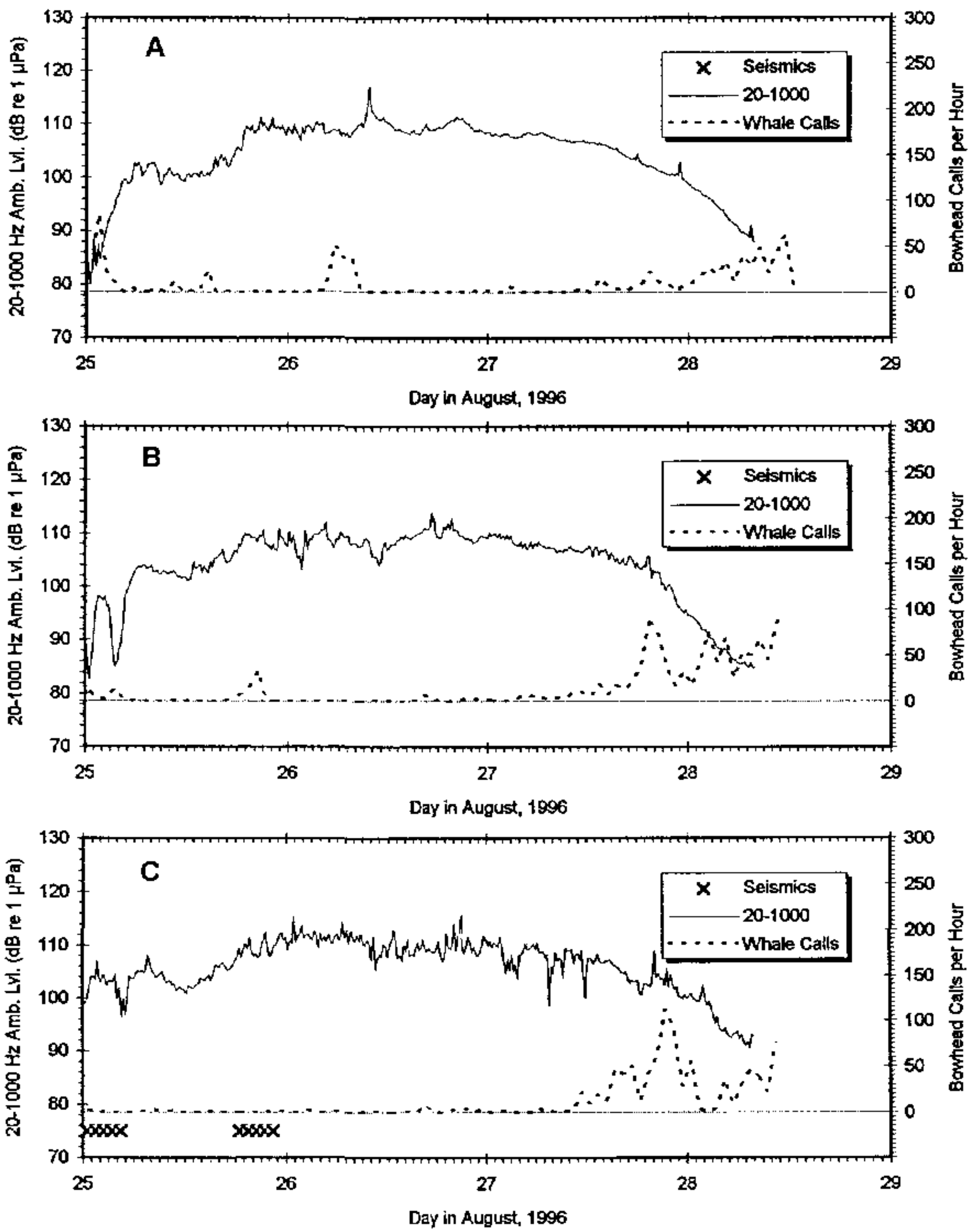


FIGURE 3.35. Ambient noise, bowhead call rates, and the presence of airgun sounds vs. time for three bottom recorders, 25-28 August 1996. *(A)* was 42 km (23 n.mi.) north of Northstar, depth 44 m. *(B)* was 30 km (16 n.mi.) north, depth 36 m. *(C)* was 24 km (13 n.mi.) north, depth 25 m. Figure 3.1 shows these locations.

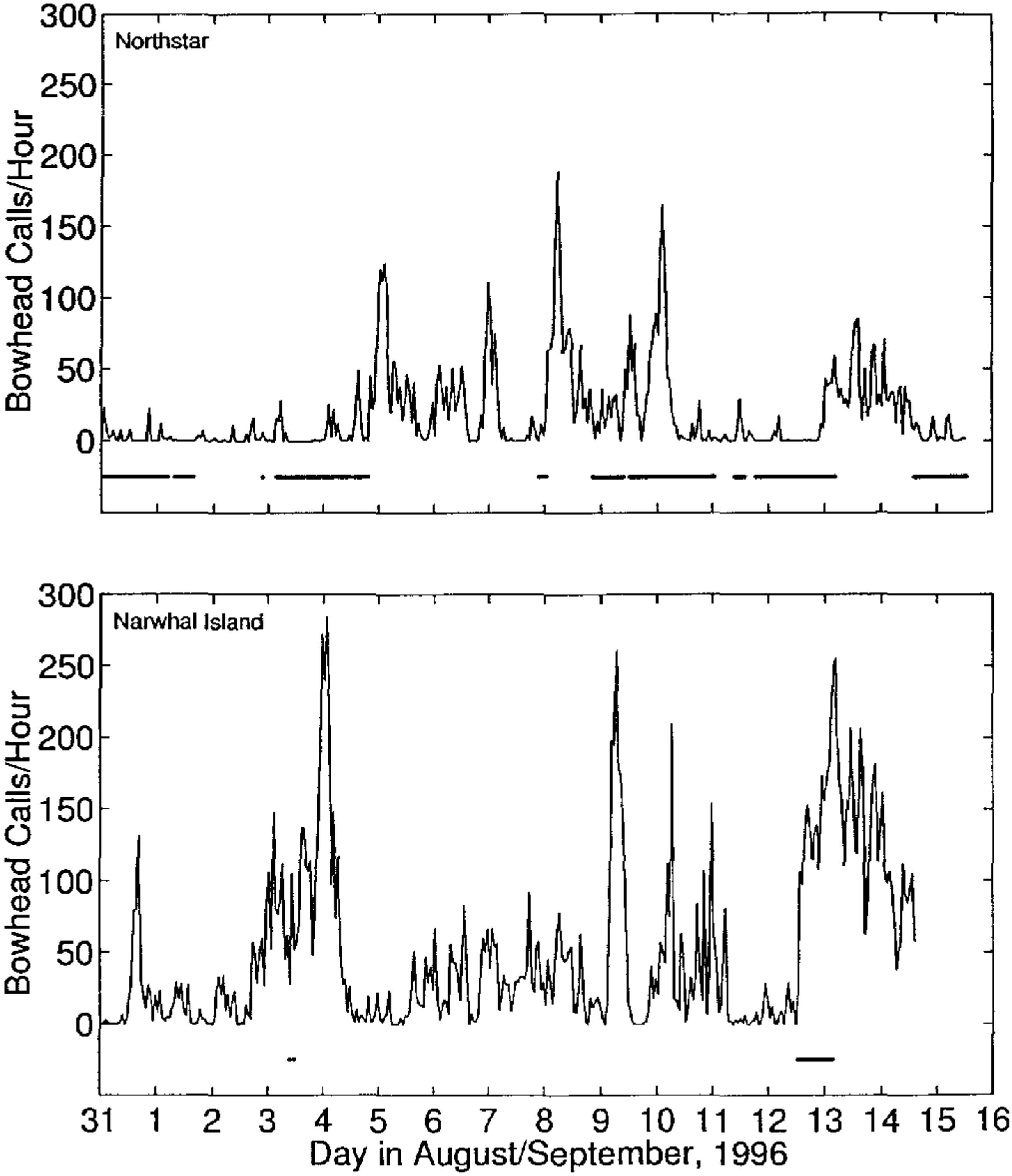


FIGURE 3.36. Bowhead whale call counts vs. time as detected via the bottom recorders north of Northstar and north of Narwhal Island. Also shown, by a line near the bottom of each panel, are the times when airgun sounds were heard at the two recorders. The tick marks on the date axis represent the start of the date in question (00:00 local time).

The total numbers of bowhead calls heard during the 351 hour period of simultaneous operation of the two long-term bottom recorders (31 August-14 September 1996) were 6920 calls off Northstar and 17,634 off Narwhal Island. Airgun pulses were heard during 49.6% of those 351 hours off Northstar and (faintly) during 5.1% of those hours off Narwhal Island. On a minute-by-minute basis, seismic pulses were detected 36.9% of the time at the Northstar recorder, and 2.1% of the time at the Narwhal Island recorder. Airgun pulses received at the Northstar recorder had low to moderate rms levels (on the order of 110 dB re 1 µPa); those received at the Narwhal Island recorder were very weak (≤79 dB re 1 µPa).

Additional analyses of bowhead call counts with and without the presence of audible airgun pulses are reported in Chapter 5, WHALES (§5.3.6).

3.9 Summary and Conclusions

This chapter describes measurements of the underwater sounds from geophysical survey operations ("seismic survey") in and near the Northstar Unit northwest of Prudhoe Bay during August and September 1996. Although boat, aircraft and ambient sounds were studied and are reported, the primary concern was with the sounds of the airgun pulses during the seismic survey itself.

The primary concerns are that the airgun sounds disturb bowheads or other marine mammals and that, as a result, the animals may be less accessible to subsistence hunters. Inupiat whalers believe that migrating bowhead whales can be displaced from their normal migratory path by as much as 30 miles (Kanayurak et al. 1997), reducing their accessibility to hunters. Also, the whalers report that bowheads are more difficult to approach when they are exposed to seismic (or other industrial) sounds. Their experience has been gained over decades of whaling along the northern coast of Alaska and is not based on the Northstar survey of 1996. As compared with the Northstar seismic survey, many of the surveys in the past have used larger arrays at greater depths and farther offshore. Thus, the characteristics and propagation of seismic pulses would not be expected to be the same during the 1996 Northstar seismic survey as during some previous surveys.

Source and received levels of seismic pulses quoted in this report and summary are, except where otherwise noted, rms pressure levels averaged over the duration of the pulse. Pulse duration is defined as the time including 90% of the pulse energy (i.e. from the time when the 5^{th} to the time when the 95^{th} percentile of the energy is received). Rms pulse levels averaged about 10 dB less than peak levels during this study.

The full array of airguns used for the 1996 Northstar program consisted of 11 airguns of volume 120 in^3 each (total airgun volume 1320 in^3) operating at 2000 psi (13.8 MPa). This is a medium-sized array. Its effective source level for horizontal propagation, computed from measurements within 200 m, is estimated to be 222 dB re 1 µPa-m for stern aspect and 213 dB re 1 µPa-m for bow aspect, with the difference perhaps due to screening by the source boat. These estimates are on an rms pressure basis. The corresponding peak source levels (horizontal plane) were about 230 and 221 dB re 1 µPa-m, or 6.3 and 2.2 bar-m peak-to-peak in the units often used by geophysicists. These peak levels are notably lower than the nominal vertical source level for the 11-airgun array, which was estimated by Painter (1996) to be 26.4 bar-m peak-to-peak or 242 dB re 1 µPa (peak). Large arrays may have peak source levels exceeding 255 dB re 1 µPa-m in the vertical and generating more than ten times the pulse pressure amplitude of the array used at Northstar.

The Northstar airguns were normally suspended at depths 3½-4 m below the surface, appropriate for very shallow water. During other surveys in deep water, the airguns are typically 6 m below the surface. Greater depth leads to more efficient sound transmission horizontally at the low frequencies associated with airguns.

The energy in the airgun pulses, as received at short horizontal distances, was mainly confined to frequencies in the 40-150 Hz band. The source array was close to omnidirectional in azimuth at 50 and 100 Hz but became increasingly directional at higher frequencies. The components of the seismic pulses below about 40-70 Hz tended to attenuate especially rapidly, with the cutoff frequency increasing with decreasing water depth near the source.

During operations with a single 120 in^3 airgun and with a partial array of six airguns, the source levels were about 23 dB and 4.5 dB lower, respectively, than that with the full 11-airgun array. These differences were consistent with the 21 and 5.3 dB differences expected on theoretical grounds when the energy from several airguns adds coherently.

The rms pressure levels from the full 11-airgun array diminished below 200, 190, 180 and 160 dB re 1 µPa at ranges not exceeding 44, 257, 1020 and 4900 m from the source, respectively. More typically, those levels were attained at respective ranges of 31, 240, 960 and 3600 m.

Because of the relatively shallow source and the shallow water in the survey area, energy at low frequencies was dissipated rapidly during propagation, leading to an unusually high apparent spreading loss rate of close to 40 dB/decade at long ranges. Based on the fitted curve in Figure 3.22, the received levels, on an rms pressure basis, are expected to be 160 dB re 1 µPa at distance 2.6 km, 132 dB re 1 µPa at 10 km, 116 dB at 20 km, 106 dB at 30 km, and 97 dB at 40 km. Variability around these values may be ±10 dB or more, especially at distances greater than 5 km. The longest distance where seismic pulses were received and measured during this study was 67 km (36 n.mi.). There, the received rms pulse level was only 77 dB re 1 µPa. That received level would be well below the natural background noise and undetectable during all but the quietest periods.

Ambient noise measurements near Northstar were made independently by three means: boat-based hydrophones, sonobuoys, and two widely-separated bottom-mounted autonomous recorders. The measurements were not all made at the same times. The measurements via hydrophones occurred during the last half of August, those via sonobuoys were made sporadically during the first half of September, and the bottom recorder measurements were continuous from 31 August until 14 or 15 September. The results were all comparable, however, with median broadband (20-1000 Hz) levels of 100 dB re 1 μPa from the hydrophones, 103 dB from the sonobuoys, and 105 and 106 dB from the two bottom recorders. These levels are similar to levels expected in the open ocean with sea states 4-5 (Beaufort force 5-6). These levels were higher than the median levels measured in the same general area in three prior years (95 dB re 1 μPa). The presence of a significant number of ice floes, with even moderate wave action, may account for the high levels.

Continuous recordings by the bottom recorders included sounds during all weather conditions. Ambient noise levels increase with higher winds and waves. The boat and sonobuoy data did not include severe weather cases and might be expected to have lower median levels. Another explanation for the differences in median level might be that ambient noise levels tended to increase during freeze-up.

Figure 3.37 shows the distances at which the received levels of the seismic pulses would be expected to diminish below the 50-400 Hz ambient noise levels (5th, 50th and 95th percentiles) at times with relatively good, typical and poor sound propagation. Chapter 5, WHALES, discusses this information in relation to the distribution of bowhead whales as observed during 1996 (see Fig. 5.47).

Sounds of boats operating as part of the survey were found to be moderate in level compared to vessel sounds generally. The strongest boat sounds measured at Northstar came from *Sag River* pushing barge 216 at speed 5.8 knots. *Sag River*'s propellers are not in Kort nozzles and would be expected to radiate more sound than a comparable vessel with shrouded propellers.

Sounds of overflights by the Twin Commander 680FL aerial survey aircraft were also measured 10 m below the water's surface as the aircraft flew over at various altitudes from 150-760 m (500-2500 ft). These sounds were several decibels stronger than previously-measured sounds from a Twin Otter performing similar overflights. The Commander's sounds were dominated by a harmonic family of tones related to the propeller blade rate; the fundamental frequency varied from 106 to 112 Hz.

Whale calls detectable in the signals recorded by the two widely-separated autonomous bottom recorders were counted for the 14.6-day period of simultaneous recordings (31 Aug.-1 Sep.) During that time, a total of 6920 calls were detectable via the recorder near Northstar, while 17,634 calls were detectable via the recorder 45 km to the ESE off Narwhal Island. Airgun pulses were received at the Northstar recorder 36.9% of the time at low to moderate mean-square levels (on the order of 110 dB re 1 μPa). Airgun pulses were received at the Narwhal Island recorder only 2.1% at the time, and those pulses were very weak (≤79 dB re 1 μPa). Further analysis of these data is given in Chapter 5, WHALES (§5.3.6).

Several conclusions may be drawn regarding the results of the acoustics studies at Northstar in 1996. From the perspective of whales migrating WNW parallel to the coast,

- the ambient noise levels were a few decibels higher than might have been expected. This would reduce the signal-to-noise ratios ("prominence") of the airgun pulse sounds by a few

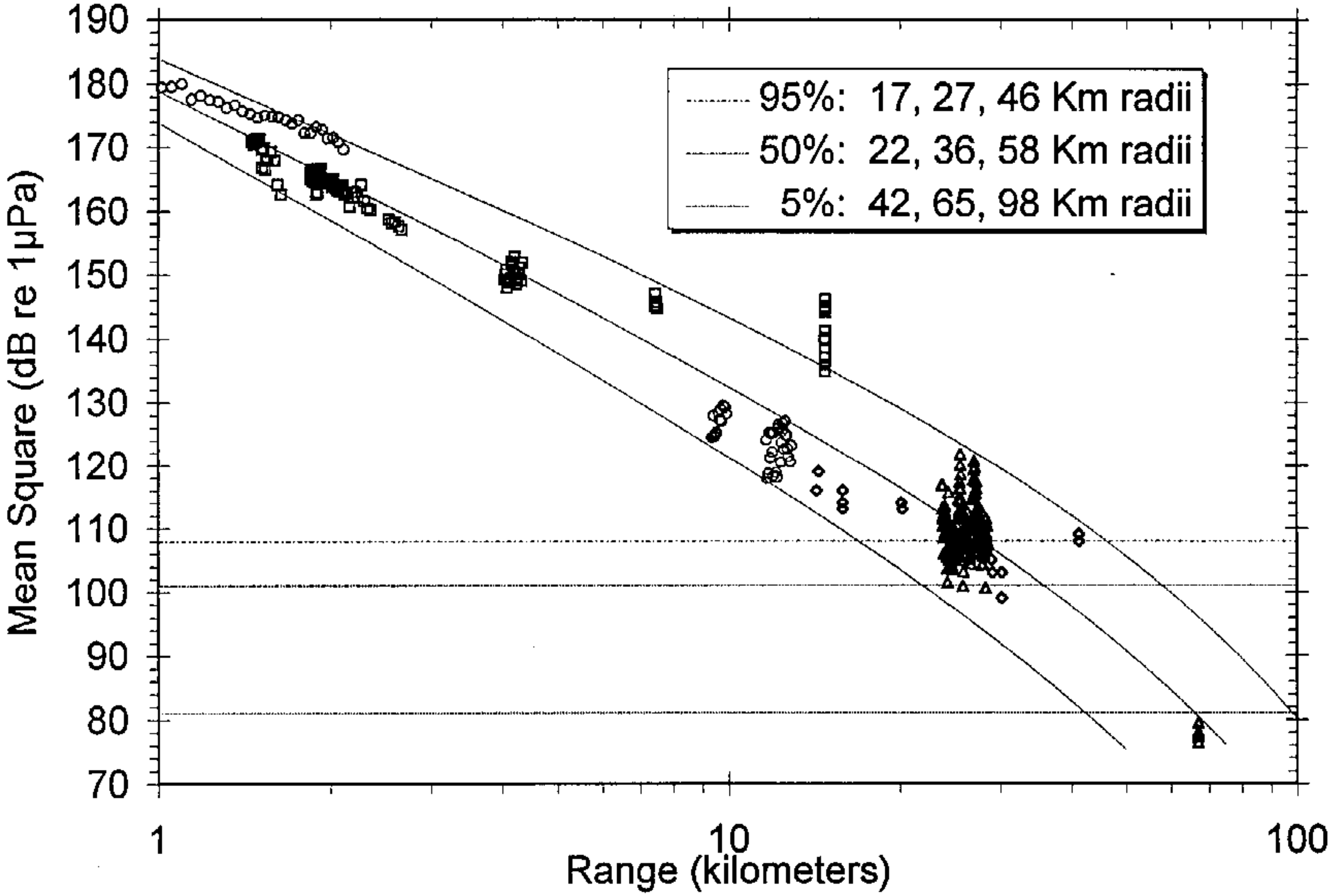


FIGURE 3.37. Rms pulse levels received at long range and fitted regression curve (from Fig. 3.22). Also shown are nominal curves for received levels with good propagation (upper curve) and poor propagation (lower curve). Horizontal lines show ambient noise levels (5th, 50th and 95th percentiles) for the 50-400 Hz band, which contains most of the pulse energy as received at long range. The intercepts of the "good, typical and poor" received level vs. range curves with the three ambient noise levels (shown in box) define radii from the source within which the received levels are expected to be heard by bowhead whales under those propagation and ambient noise conditions.

decibels, and would reduce the maximum detection distances somewhat. ▸ The airgun array being used was smaller than typically used during previous seismic surveys farther offshore in deeper water, thereby reducing the source level of the airgun sounds. ▸ The survey was being conducted in relatively shallow water, resulting in higher attenuation of the dominant low frequency sound in the pulses and correspondingly lower levels in the whale migration corridor offshore of the area of seismic exploration. ▸ The most distant airgun sounds detected had traveled 67 km (36 n.mi.) and were barely above the quietest background level observed during the field program; the maximum detection distance on a more typical day was about 36 km (19 n.mi.).

3.10 Acknowledgements

Everyone on the barge *Arctic Endeavor* helped with the acoustics field work. The crew of "sound boat" *La Brisa* was especially helpful: Pete Crosbie, Ted Whip, Rob Hulse, Bob Lockman and Alan Arrigoni. Jeff Hastings and Scott Nish, Northern Geophysical of America field operations directors, went out of their way to coordinate their activities with our data collection needs. Howard Claiborne helped with a variety of problem solutions. Juan Gardner, Pelagos Navigation, assisted immeasurably with position logging on the *La Brisa*. The LGL and Inupiat marine mammal observers on the *Point Barrow* were helpful. Tess Carr, BPX(A) environmental coordinator at Prudhoe Bay during our time on the barge, provided valuable support. The Crowley Marine crew on *Sag River* was indispensable during bottom-unit retrieval in mid-September. Dr. Bill St. Lawrence and Bob and Tena Lewellen provided weather and ice forecasts and data.

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4. SEALS[1]

4.1 Introduction

This chapter reports primarily on the numbers, distances from the seismic boat, and behavior of seals that were observed during boat-based marine mammal monitoring from 24 July through 18 September 1996. Emphasis is given to the numbers and behavior of seals seen within 150 m of the seismic source vessel, 150-250 m away, and >250 m away. These distance criteria match the shutdown radii specified in the Incidental Harassment Authorization (IHA) issued to BPXA by the National Marine Fisheries Service (NMFS) for this project.

The focus here is on the differences in seal numbers, distances and behavior at times when the source vessel was underway but not shooting seismic versus times when the airguns were firing. The source vessel itself, even when not conducting seismic activities, may have had some effect on seals. However, in the absence of airgun operations, this potential boat effect would not differ from the effect of any similar tugboat.

Although a major aerial survey program for marine mammals was done in and around the Northstar area during September 1996, the aerial surveys were designed to detect whales. Survey altitudes were 900-1500 ft (275-460 m)—too high for reliable detection of pinnipeds at the surface. Seals were seen and recorded only opportunistically during the aerial surveys. These data are presented briefly in section 4.3, along with a general discussion of the status and annual cycle of each seal species. That general introductory material also summarizes seal sightings during aerial surveys of the central Alaskan Beaufort Sea done during the late summers and autumns of 1979 through 1995 by MMS and LGL.

4.2 Methods

Boat-Based Monitoring

Observation Procedures.—Three or four observers were assigned to the source vessel at all times during the 24 July through 18 September period of seismic operations. These included 2 or 3 biologists whose qualifications had been submitted in advance to NMFS, plus an Inupiat observer-communicator. Observation work was scheduled in 4-hour shifts, with each observer normally being responsible for two 4-hour shifts (separated by at least 4 hours) during a 24 hour period. Normally, one or two of the observers lived aboard the source vessel (*Point Barrow*) and the others commuted back and forth via crew boat to the camp barge (*Arctic Endeavor*) every 12 hours.

A fourth observer shared the observation duties during the period 31 August through 17 September. During that time, preparations were being made to deploy a second source

[1] By Ross E. Harris, Gary W. Miller, Robert E. Elliott and W. John Richardson, LGL Ltd.

vessel (the *Hippo*). The additional observer, a biologist, was present to allow simultaneous observations from both source vessels if needed. In actuality, the *Hippo* was never used as an airgun source vessel. The presence of an additional biologist during the whale migration season also provided greater flexibility in personnel scheduling during times when the Inupiat observer-communicators had other communication responsibilities (as required by the Conflict Avoidance Agreement).

At all times while shooting was underway, or when it was expected to begin within the next 30 minutes, the on-duty observer watched continuously for mammals. Observations were made from the glass-enclosed wheelhouse of the *Point Barrow*, which was the highest vantagepoint on the vessel. Eye level was about 7.5 m above the water. The wheelhouse afforded a 360° view with only minor obstructions to vision toward the stern. During approximately 5-10% of the time while monitoring was underway, a second member of the monitoring crew was also on duty in the wheelhouse.

The observer scanned around the vessel using 7 x 50 Fujinon FMTRC-SX binoculars.[2] The binoculars included a reticle to measure depression angle relative to the horizon—an indicator of distance. The compass built into these binoculars was not useful on the steel vessel, but directional information was readily available in the wheelhouse.

Observers also used a Bushnell Lytespeed 400 laser rangefinder with 4x optics to test and improve the observers' abilities for visually estimating distances to objects in the water. This Class 1 eye-safe device was not able to measure distances to seals more than about 70 m away. However, it was very useful in improving the distance estimation abilities of the observers at distances up to about 600 m—the maximum range at which the device could measure distances to highly reflective objects such as other vessels.

During July and much of August there was no total darkness, and normal visual observations were possible during all hours when shooting was underway. Thereafter the nights rapidly became longer, such that by the end of operations on 18 September there were about 10.5 hours of total darkness each night. The IHA and other permits contained no requirement for seismic operations to be suspended at night or during periods of poor visibility, and seismic work continued at such times. At night, the observers used both the 7 x 50 binoculars and a Bushnell/ITT Night Ranger 250 binocular night vision device (NVD) equipped with up to 6-power lens adapters. A Bushnell/ITT Night Ranger 150 monocular NVD was also available for backup but was not used. Lights in the wheelhouse and on the outside of the vessel were usually on at night, and these reduced the effectiveness of the NVD. The IHA required nighttime observations by the monitoring personnel only at times while the array was being powered up. However, in practice, the monitoring personnel attempted to observe at all times, night or day, when the airguns were operating or were

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[2] The requirement in the original IHA for Big-Eye binoculars was deleted by a modification dated 28 July 1996.

expected to start operating within the next 30 minutes. Notwithstanding the use of the NVD, the observers' abilities to detect marine mammals were severely reduced at night.

***Data Recorded*.**—While on watch, the marine mammal observer regularly recorded, on a data sheet, information regarding seismic status and environmental conditions. Additional data were recorded for marine mammal observations. For all records, the date, time, position (latitude, longitude), vessel heading, vessel speed and observer name were recorded. The latitude, longitude, heading and speed, along with information about seismic activity, were available from the computer monitor in the wheelhouse. Operational activities that were recorded were the "seismic state" (no airguns, single airgun, partial array [2-7 guns], full array [8-11 guns], ramp up, seismic testing) and/or the number of guns operating, and whether or not the shooting was on a source line or OBRL line. Only a single airgun was in use on OBRL lines (see §2.2, "Equipment and Operations"). Environmental conditions that were recorded included ice cover within about 1 km of the seismic source vessel (percent cover, primary ice type, secondary ice type), wind speed (from the boat's guage) and direction, sea state (Beaufort Scale), cloud cover and thickness, visibility, obstructions to visibility (e.g., fog, snow), and glare. Standardized codes were used for most of these records, but written descriptive comments were often added.

For each marine mammal sighting, the following information was recorded: species, number of individuals seen, sighting cue, age if evident, behavior, reaction, heading, bearing, distance, and seismic status. No cetaceans were seen from the seismic vessel, so the following description of the data recorded is limited to items relevant for seals. The sighting cue was the feature that initially drew the observer's attention to the seal. These cues included the head or body breaking the water surface, or a splash. For seals, no age determinations were possible and this category was never used.

Several standardized behavior and reaction categories were used. "Behavior" was the behavior of the seal when initially sighted. The "reaction" referred to behaviors observed subsequently. *Behavior categories* that applied to seals were dive, swim, mill, thrash, look, and unknown. Swimming involved directed movement, unlike milling. Thrashing was a particularly active swimming behavior at the surface. *Reaction categories* were none (i.e., no change in behavior), dive, swim away (=avoidance), swim toward (=approach), swim parallel, look, and other (with description). Two types of dives by seals were distinguished in the data from mid-August onward: "sink" and "front dive". Seals often floated in a vertical posture and then simply sank, tail first, straight back down into the water. Seals that "front dove" went below the surface head first. Seals that "looked" floated at the surface in a vertical posture and faced the source vessel. If it was possible to continue making observations of a seal after the initial sighting, this was done. To aid in subsequent analysis, a brief written description of seal behavior and sighting circumstances often was made, time permitting.

The seal's direction of movement (heading) and position relative to the boat (bearing) were recorded by reference to the boat's heading. Directions relative to the boat were estimated as hours on a clock face; "1 o'clock", for example, was 30 degrees off the boat's trackline to starboard. An estimate was made of the radial distance of the seal from the source vessel. Usually there was sufficient time to estimate the distance more accurately using the 7 x 50 reticle binoculars. Occasionally there was only enough time to estimate the distance by eye. The distance and bearing to the seal were measured from the wheelhouse, which was approximately 30 m ahead of the airgun array.

Shutdown Procedures.—The definitions of the safety zones for seals and cetaceans, and the procedures that were followed when a marine mammal was sighted within the safety zone, are described in §2.3, "Mitigation Measures". The IHA called for the airguns to be shut down when seals were within certain safety radii. These were defined based on the distances where received levels of seismic pulses were expected to be near 190 dB re 1 μPa, based on a "mean square" or rms basis over the effective duration of the pulse (see section 3.2).

Up to 30 August, the safety zone was defined as an area with radius 150 m. This was based on estimates of received level vs. distance from the airguns derived prior to the field season. Direct acoustic measurements of received levels vs. distance were obtained during mid-late August 1996 (see Chapter 3, PHYSICAL ACOUSTICS MEASUREMENTS).

On 30 August, based on those new measurements, the safety radius was changed to 250 m when an airgun array was in use, but remained as 150 m during single-airgun operations. Subsequent analysis of the physical acoustics data has confirmed that 250 m is a good estimate of the maximum radius within which the rms pulse level was 190 dB re 1 μPa or higher during airgun array operations. The actual 190 dB radius during single airgun operations was much less than 150 m (see Chapter 3).

When one or more airguns were operating, the observer determined from the distance estimate whether the seal was within, or about to come within, the safety zone (150 m radius up to 30 August; thereafter 150 m for single airgun and 250 m for airgun array, as described above). If the seal was within, or about to be within, the safety zone while airgun(s) were operating, the observer instituted the shutdown provisions described in §2.3. A total of 135 shutdowns were initiated during the 1996 seismic program because of seals sighted within, or about to enter, the safety zone.

Aerial Surveys

Seals were also recorded when seen during the aerial surveys conducted in the 1-21 September 1996 period. Because of weather limitations on some dates, there was aerial survey coverage on 14 days from 3 to 20 September. This included coverage of most or all of the pre-planned survey grid on 9 days and partial coverage on 5 additional days. The survey route and daily coverage are shown in Chapter 5, WHALES. The survey aircraft operated at altitudes of 900 to 1500 ft above sea level (275 to 460 m), as described in Chapter 5.

Ringed seals in the water are very difficult to see from those altitudes, and only a small and highly variable proportion of the numbers present are detectable. Sightability varies drastically depending on sea state, lighting, and ice conditions. Thus, no quantitative data on ringed seals were obtainable from the aerial surveys. However, the results do confirm the well-known common occurrence and widespread distribution of the species in the area. The aerial survey results are believed to be somewhat more meaningful for the larger and easier-to-sight bearded seals.

4.3 Status and Aerial Survey Results

LGL and Greeneridge (1996) include a summary of late summer and autumn sightings and distribution of seals in the Northstar region during the years 1979 to 1995, based on aerial surveys by the Minerals Management Service and its contractors (1979-1995) and by LGL Ltd (1982, 1984-85, 1995). This information is updated here with observations from the 1996 aerial surveys and the combined results are discussed.

Ringed Seal, *Phoca hispida*

Introduction.—Ringed seals are year-round residents in the Beaufort Sea and are the most consistently encountered of the seals in the project area. The estimated population of ringed seals in the Bering-Chukchi-Beaufort area is 1-1.5 million (Kelly 1988; Small and DeMaster 1995), with an estimated 80,000 seals found in the Beaufort Sea during summer and 40,000 during winter (Frost and Lowry 1981). The Alaska stock of ringed seals is not classified as a strategic stock. The worldwide population of ringed seals is estimated at 6-7 million (Stirling and Calvert 1979).

During winter months, the ringed seal occupies the land-fast ice and offshore pack ice of the Bering, Chukchi and Beaufort seas. In winter and spring, the highest densities of ringed seals are found on stable shore-ice. However in some areas where there is limited fast ice but wide expanses of pack ice, including the Beaufort Sea, Chukchi Sea and Baffin Bay, total numbers of ringed seals on pack ice exceed those on shore-fast ice (Burns 1970; Stirling et al. 1982; Finley et al. 1983). Ringed seals maintain breathing holes in the ice by using their claws and maintain lairs in accumulated snow (Smith and Stirling 1975). Ringed seals give birth in these lairs starting in early April and nurse their pups for 4-6 weeks. The highest densities of breeding ringed seals occur in areas of landfast ice. Mating occurs in late April and May.

During summer, ringed seals are found dispersed throughout open water areas, although in some regions they move into coastal areas. In the eastern Beaufort Sea and Amundsen Gulf, ringed seals concentrate in similar offshore areas from one year to the next and are often found in large groups in these areas (Harwood and Stirling 1992). It appears that these concentrations are found in areas of greater food abundance that may be related to oceanographic features. Similar summer concentrations have not been reported in the central and western Beaufort Sea. Ringed seals are significant predators of small fish and zooplankton. The ringed seal is also the principal food of polar bears (Stirling 1974; Kingsley 1990) and is important to other predators such as the arctic fox (Smith 1976).

In addition to local movements in response to seasonal changes in ice conditions, there may be large scale movements of ringed seals into and out of the Beaufort Sea. Smith and

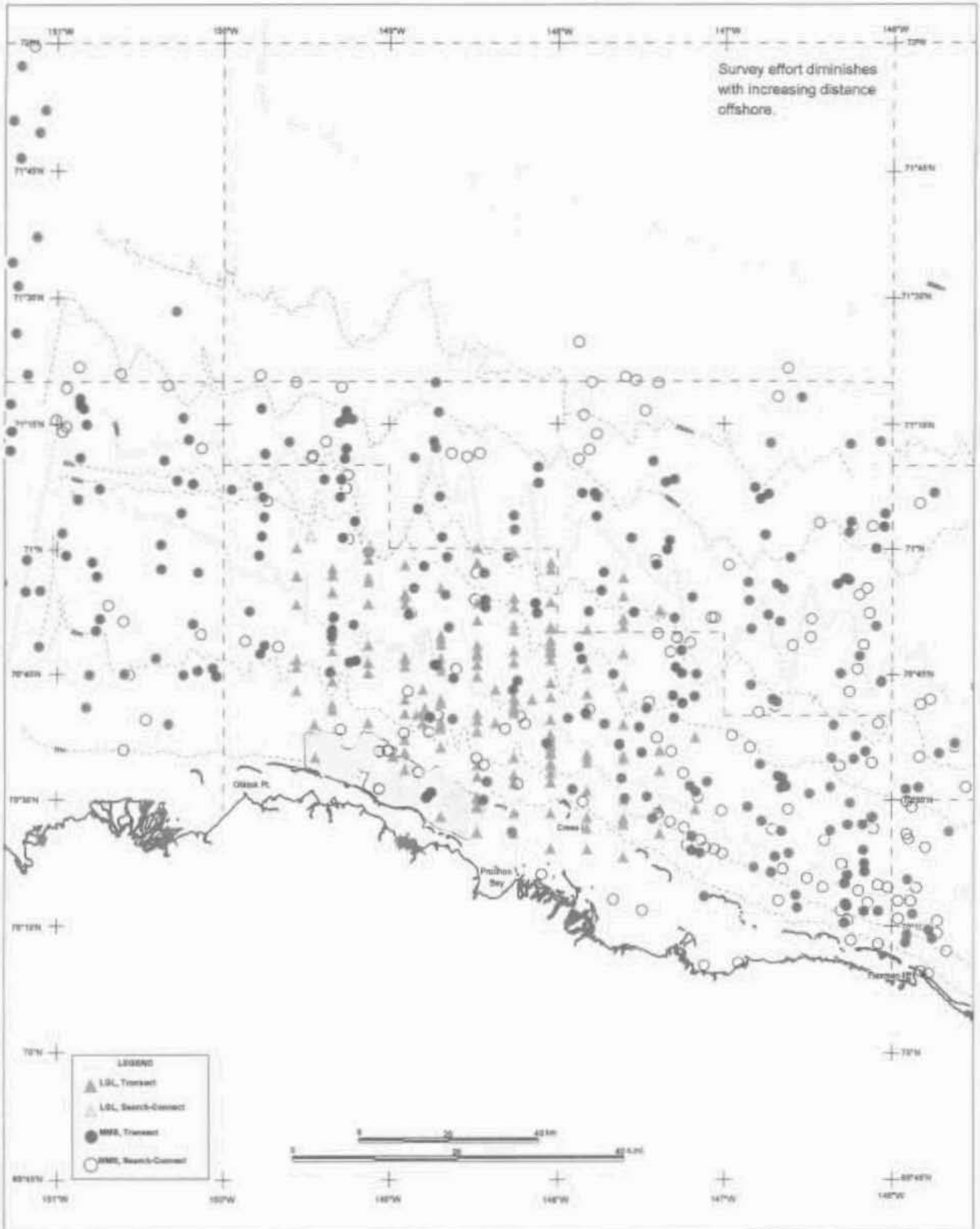

FIGURE 4.1. Ringed seal sightings in the central Alaskan Beaufort Sea during late summer and autumn of 1979-95 based on MMS and LGL aerial surveys. Shaded area is the Northstar area and nearby waters where seismic surveys were done during mid-August through mid-September 1996. See §5.2 for explanation of "Transect" vs. "Search-Connect" sightings. Faint dashed lines show boundaries of MMS survey blocks (see Fig. 5.2 for block numbers).

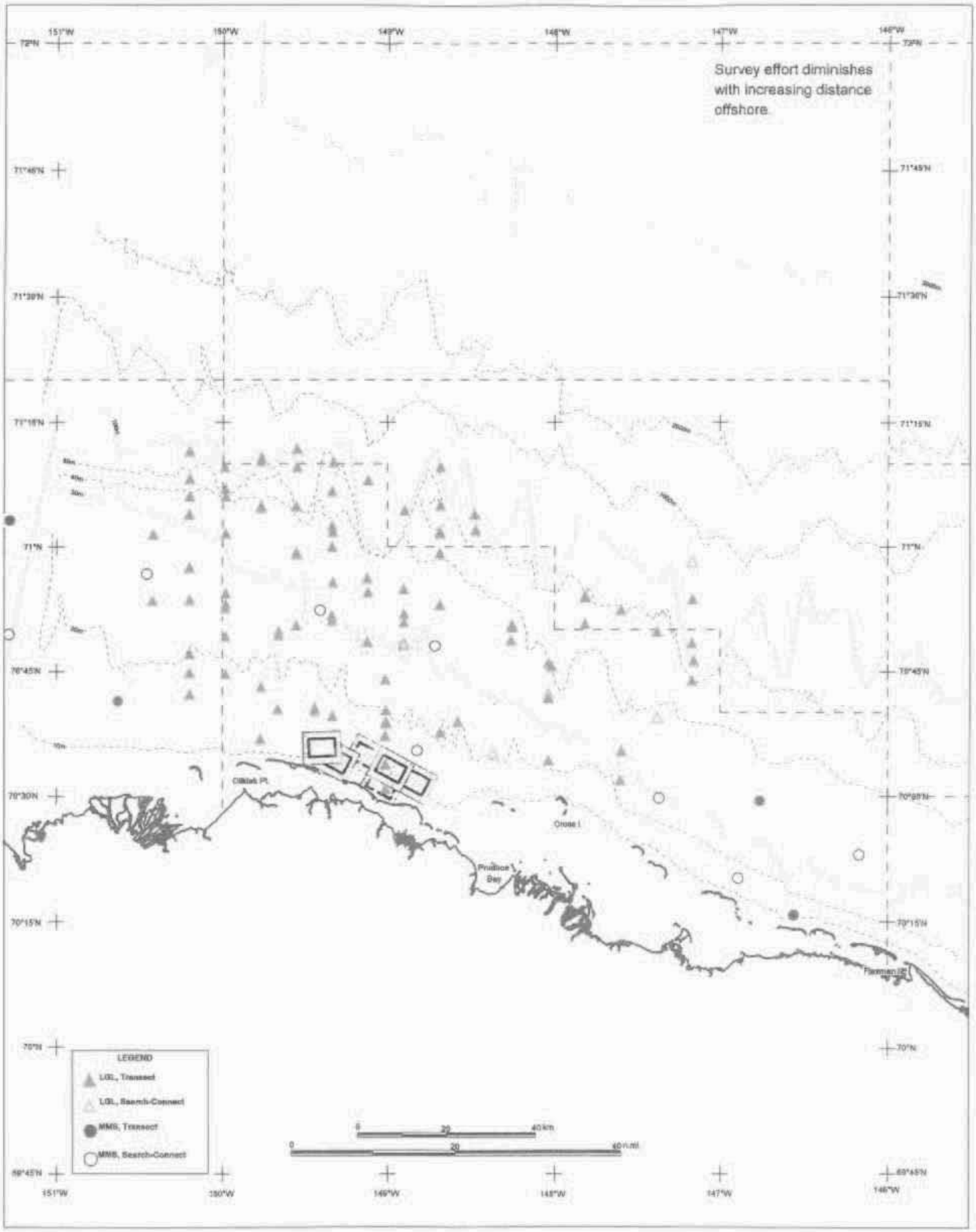

FIGURE 4.2. Ringed seal sightings in the central Alaskan Beaufort Sea during late summer and autumn of 1996 based on MMS and LGL aerial surveys. "Patches" where seismic work was done during the aerial survey period are shown. Otherwise plotted as in Fig. 4.1.

Stirling (1978) described a westward migration of subadult seals in the eastern Beaufort Sea prior to autumn freeze-up and a small number of long distance movements of marked individuals have been documented. However, the nature and extent of these movements are not well understood (Smith 1987; Kelly 1988).

Ringed seal surveys are conducted during late winter and spring; quantitative surveys have not been possible during late summer. Only a very small proportion of the ringed seals present in open water are seen during high-altitude aerial surveys designed to search for whales. Therefore, densities and numbers of this species in the project area during late summer and autumn cannot be estimated based on season-specific data. Densities of ringed seals on shore-fast ice between Lonely and Oliktok points averaged 0.54/km^2 in 1970 (Burns and Harbo 1972) and 0.17 to 0.61/km^2 from 1975 to 1977 in areas without on-ice seismic activity (Burns et al. 1981).

In general, ringed seals are common and widely dispersed within and near the project area at this season.

Aerial Survey Results.—Ringed seal sightings during the MMS and LGL aerial surveys are shown in Figure 4.1 (1979-95) and Figure 4.2 (1996). During late summer and autumn, ringed seals were observed to be widely distributed throughout the central Alaskan Beaufort Sea. However, relatively few were observed in the Northstar seismic area either in 1996 or in earlier years. In general, the aerial surveys suggest that ringed seals tended to prefer waters deeper than about 20 m, i.e. they may prefer waters farther offshore than the Northstar region.

Ringed seals in the water are difficult to detect from the altitudes at which most of the aerial surveys were flown. This is especially true when observers are searching primarily for whales. Ringed seals were undoubtedly much more abundant in the region than the late summer/autumn aerial survey data suggest. Detailed analyses and quantitative interpretations of the aerial survey data are not warranted because of the known serious biases of high-altitude surveys in detecting ringed seals in open water.

Bearded Seal, *Erignathus barbatus*

Introduction.—The Alaska stock of bearded seals, which occupies the Bering, Chukchi, and Beaufort seas off Alaska, may consist of about 300,000-450,000 individuals (MMS 1996). However, Small and DeMaster (1995) indicate that, "Until additional surveys are conducted, reliable estimates of abundance for the Alaska stock of bearded seals are considered unavailable." Nevertheless, the Alaska stock of bearded seals is not classified by NMFS as a strategic stock.

The bearded seal is the largest of the northern phocids. It is primarily a bottom feeder and its preferred habitat is, therefore, areas with water less than 200 m deep. However, bearded seals apparently also feed on ice-associated organisms when they are present; a few bearded seals have been found associated with ice in water depths much greater than 200 m.

Seasonal movements of bearded seals are directly related to the advance and retreat of sea ice and to water depth. During the winter, most bearded seals in Alaskan waters are found in the Bering Sea. In the Chukchi and Beaufort seas, favorable conditions are more limited and consequently bearded seals are less abundant there during the winter (Nelson et al., n.d.). In spring, between mid-April and June, as the ice recedes, seals overwintering in the Bering Sea migrate northward through the Bering Strait. During the summer most are found near the widely fragmented margin of multi-year ice covering the continental shelf of the Chukchi Sea and in nearshore areas of the central and western Beaufort Sea. In Alaska, bearded seals do not use coastal haul outs as bearded seals do in some other parts of their range.

In some areas, bearded seals are associated with the ice year-round; however, because bearded seals are primarily benthic feeders, they usually move into open water areas when the pack ice retreats to areas with water depths greater than 200 m. During the summer, when the Bering Sea is ice-free, the most favorable bearded seal habitat is found in the central or northern Chukchi Sea along the margin of the pack ice. Suitable habitat is limited in the Beaufort Sea, where the continental shelf is comparatively narrow and the pack-ice edge frequently occurs seaward of the shelf and over water too deep for feeding (Nelson et al., n.d.). The preferred habitat in the western and central Beaufort Sea during the open water period is the nearshore area seaward of the scour zone.

Aerial Survey Results.—Few bearded seals were observed in or adjacent to the Northstar seismic area during aerial surveys in late summer and autumn. Bearded seals were, however, widely distributed in the surrounding region (Fig. 4.3, 4.4). Bearded seals were sighted in waters ranging from <10 m (rarely) to >1000 m deep. Although bearded seals are known to prefer relatively shallow waters in which they can feed on benthic organisms, a few of the sightings recorded during the MMS surveys, which ranged farther north than the LGL surveys, were in waters north of the continental shelf. A few MMS sightings of bearded seals in prior years were in waters more than 3000 m deep and at latitudes north of 71°30'N (Fig. 4.3).

During 1996, 35 bearded seal sightings and 39 individuals were recorded during the Northstar aerial surveys done by LGL (Fig. 4.4). No bearded seals were reported during MMS surveys of the corresponding region (146°00'W-150°30'W longitudes) during 1996.

An analysis of 1979-95 bearded seal sighting data from the central Alaskan Beaufort Sea showed that sightings of bearded seals declined steadily as the late summer/autumn season progressed. The average sighting rate was 0.27 sightings per 100 km of survey in the 16-31 August period, 0.10 and 0.09 per 100 km during the first and last halves of September, and 0.05 and 0.04 per 100 km during the first and last halves of October (LGL and Greeneridge 1996). Some portion of the bearded seals that inhabit the Alaskan Beaufort Sea during the summer migrate into the Bering Sea to spend the winter months.

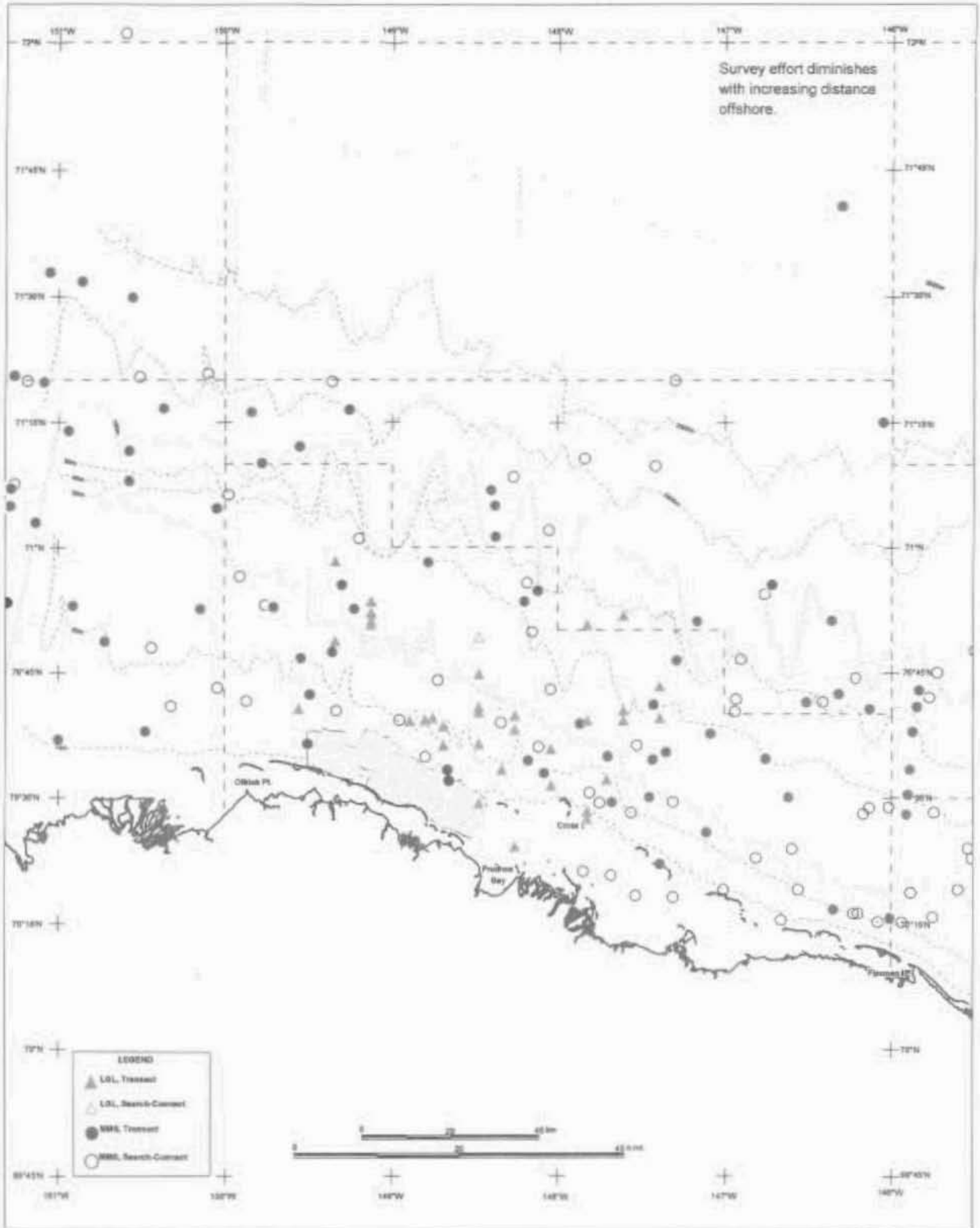

FIGURE 4.3. Bearded seal sightings in the central Alaskan Beaufort Sea during late summer and autumn of 1979-95 based on MMS and LGL aerial surveys. Plotted as in Fig. 4.1.

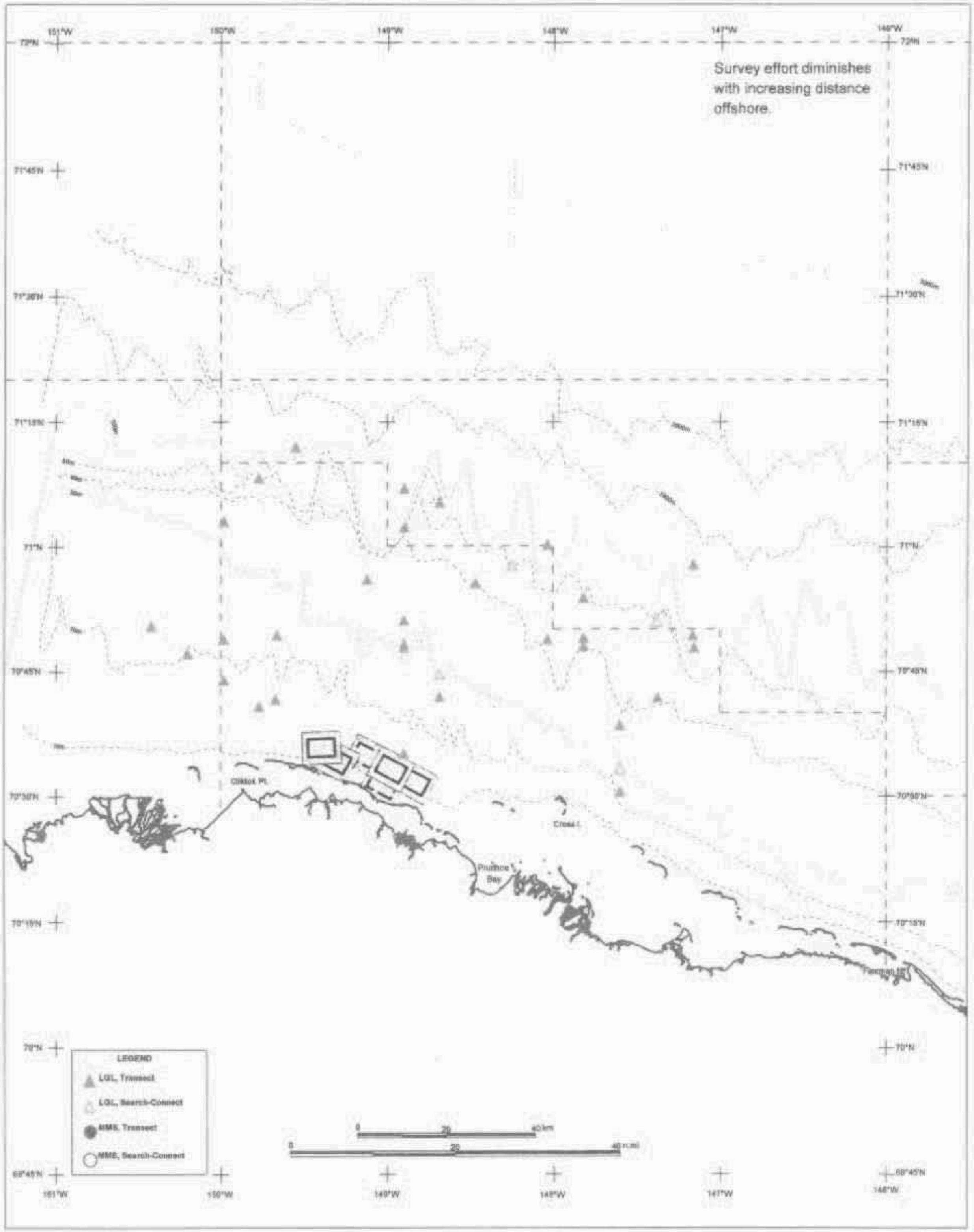

FIGURE 4.4. Bearded seal sightings in the central Alaskan Beaufort Sea during late summer and autumn of 1996 based on MMS and LGL aerial surveys. "Patches" where seismic work was done during the aerial survey period are shown. Otherwise plotted as in Fig. 4.1.

Spotted Seal, *Phoca largha*

Introduction.—An early estimate of the size of the world population of spotted seals was 370,000-420,000, and the size of the Bering Sea population, including animals in Russian waters, was estimated to be 200,000-250,000 animals (Bigg 1981). A reliable estimate of the size of the entire Alaska stock is currently not available because of incomplete sampling (Small and DeMaster 1995). Nevertheless, the Alaska stock of spotted seals is not classified as a strategic stock by NMFS (Small and DeMaster 1995).

During spring, when pupping, breeding, and molting occur, spotted seals are found along the southern edge of the sea ice in the Okhotsk and Bering seas. In late April and early May, adult spotted seals are often seen on the ice in female-pup or male-female pairs. Subadults may be seen in larger groups of up to two hundred animals. During the summer, spotted seals are found primarily in the Bering and Chukchi seas, but some range into the Beaufort and perhaps into the East Siberian seas (Lowry, n.d.). At this time of year, an unknown proportion haul out on mainland beaches and offshore islands and bars (Frost et al. 1993). Recent tagging studies during summer at Kasegaluk Lagoon, in the Chukchi Sea, indicate that spotted seals may travel long distances offshore to feed, and that a very small proportion (<10%) may be hauled out at any one time (Frost et al. 1993). In summer, they are rarely seen on the pack ice, except when the ice is very near to shore. The seals are commonly seen in bays, lagoons and estuaries. As the ice cover thickens with the onset of winter, spotted seals leave the northern portions of their range and move into the Bering Sea.

A few spotted seal haul-outs occur in the central Beaufort Sea in the deltas of the Colville and (at least formerly) the Sagavanirktok rivers. Historically these sites supported as many as 400-600 seals, but in recent times <10 seals have been seen at any one site (J.W. Helmericks, pers. comm.; S.R. Johnson, LGL Ltd., unpubl. data). In total, there are probably no more than a few tens of spotted seals along the coast of the central Beaufort Sea during summer and early fall.

Aerial Survey Results.—Spotted seals were not identified during MMS and LGL aerial surveys of the central Alaskan Beaufort Sea during the late summers and autumns of 1979-96. However, three spotted seals were identified during boat-based monitoring (see below).

4.4 Boat-Based Monitoring Results

Survey Effort

Marine mammal observers were on watch during all periods with airgun operations, and during many periods when the source vessel was underway but not shooting seismic. The numbers of hours of observation varied throughout the study period accordingly. Watches were conducted during daylight and, later in the season when there was overnight darkness, during the night as well. The hours of survey effort, categorized by week, seismic category, and darkness vs. daylight, are summarized in Table 4.1. The hours of survey effort shown

TABLE 4.1. Survey effort: the numbers of hours of observation from the source vessel by marine mammal observers. Effort is categorized by week, seismic category, and darkness vs. daylight periods. Hours of survey effort during seismic activity also are the total hours of all seismic activity as observers were on watch during all periods of seismic activity. "Partial Array" = 2-7 guns firing; "Full Array" = 8-11 guns firing.

	HOURS OF OBSERVATION									
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	
SEISMIC STATE	Jy 24 - Jy 27	Jy 28 - Au 3	Au 4 - Au 10	Au 11 - Au 17	Au 18 - Au 24	Au 25 - Au 31	Se 1 - Se 7	Se 8 - Se 14	Se 15 - Se 18	TOTAL
DARKNESS										
No Guns	0.0	0.0	0.0	4.2	11.2	4.5	8.1	7.4	2.3	37.8
Single Gun	0.0	0.0	0.0	1.4	2.2	0.7	0.6	5.1	0.0	9.9
Partial Array	0.0	0.0	0.0	0.7	1.6	1.6	1.2	3.7	5.7	14.4
Full Array	0.0	0.0	0.0	2.4	9.3	7.1	10.4	20.3	14.1	63.6
Ramp Up	0.0	0.0	0.0	0.0	0.5	0.7	0.5	1.7	1.4	4.8
Testing	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.9	0.1	3.2
Total	0.0	0.0	0.0	8.7	26.9	14.5	20.9	39.2	23.5	133.7
DAYLIGHT										
No Guns	27.5	38.9	26.0	56.4	48.2	14.0	13.8	29.0	8.6	262.3
Single Gun	2.6	27.9	30.8	17.6	7.1	0.1	4.8	4.3	0.0	95.3
Partial Array	0.4	15.5	24.4	11.6	4.3	2.6	2.8	2.0	8.4	72.0
Full Array	4.7	59.3	61.6	35.9	26.3	14.3	15.6	34.4	17.2	269.2
Ramp Up	0.0	1.9	3.5	5.1	4.4	1.7	1.4	5.2	3.5	26.7
Testing	4.8	7.9	3.6	3.7	3.5	1.2	0.2	1.1	0.3	26.3
Total	40.1	151.4	149.9	130.2	93.8	33.8	38.6	76.0	38.0	751.9
ALL										
No Guns	27.5	38.9	26.0	60.6	59.4	18.4	21.9	36.4	10.9	300.1
Single Gun	2.6	27.9	30.8	18.9	9.3	0.8	5.5	9.4	0.0	105.2
Partial Array	0.4	15.5	24.4	12.3	5.9	4.2	4.0	5.7	14.1	86.5
Full Array	4.7	59.3	61.6	38.3	35.6	21.4	26.0	54.7	31.3	332.8
Ramp Up	0.0	1.9	3.5	5.1	4.9	2.4	1.9	6.9	4.9	31.5
Testing	4.8	7.9	3.6	3.7	5.6	1.2	0.2	2.1	0.4	29.4
Grand Total	40.1	151.4	149.9	138.9	120.7	48.4	59.5	115.2	61.6	885.6

in Table 4.1 were used to calculate the numbers of seals observed per hour in the "Species and Numbers Observed" section that follows.

Total hours of observation were 885.6. Most watches were conducted during daylight (751.9 h daylight vs. 133.7 h darkness), and the majority of the watches were during periods of airgun operations (585.5 h with airgun(s) vs. 300.1 h without). Approximately 83% (738.1 h) of the survey effort occurred while the source vessel was firing either the full array (8-11 guns, 332.8 h, 37.6%), not firing any guns (300.1 h, 33.9%), or firing a single gun (105.2 h, 11.9%). In most cases, operation of the full array occurred while shooting production lines, and operation of a single gun occurred while conducting Ocean Bottom Receiver Localization (OBRL). OBRL was done to determine the precise locations of receiver cables (see §2.2). Relatively little time was spent firing a partial array (2-7 guns), ramping up, or testing the guns.

Survey effort varied markedly from week to week, depending primarily on the effect that sea state and ice conditions had on the seismic contractor's ability to conduct the seismic work. Weeks 2 through 5, and 8, were the busiest. Together they accounted for 676.1 of the 885.6 hours of observation, or 76.3%. During late August and early September, seismic activity was limited because of frequent high sea states and large broken floes of ice that were blown into the study area. No watches were done when the source vessel was not underway.

Detection of Seals

Seals were first seen at estimated radial distances from the vessel of 2 m to 1491 m. However, most seals were first sighted within a radial distance of 250 m of the source vessel (Fig. 4.5). Only 70 (18.4%) of the 381 sightings during daylight surveys were beyond 250 m. During airgun operations, seals were first seen as close as 12 m (ramp up), 16 m (full array), 20 m (single gun), and 30 m (partial array), as measured from the wheelhouse. Seals were often seen just ahead of or alongside the source vessel. However, when airguns were in operation, seals were not seen in the area ~30 m behind the wheelhouse, where the airgun(s) were located (see Fig. 4.7B,C, later).

The detectability of seals from the source vessel undoubtedly varied with several factors, including primarily glare, sea state, and ice cover. Observers also tended to concentrate on searching for seals within or near the limit of the safety zone (initially 150 m, then expanded to 250 m on 30 August). Nevertheless, it is apparent that observers did not detect seals as effectively beyond 250 m. Also, the observers apparently missed many seals within 250 m. One indication of this is that the numbers of initial sightings in the various 50-m annuli out to 250 m were generally similar even though the areas of those annuli increased with increasing radial distance (see Fig. 4.9, below, for additional information on sightability vs. distance).

Species and Numbers Observed

A total of 422 seals were seen by the marine mammal observers on board the source vessel during the 1996 field season. Of these seals, 421 were seen during daylight. Only one seal was seen during the 133.7 hours of nighttime observations.

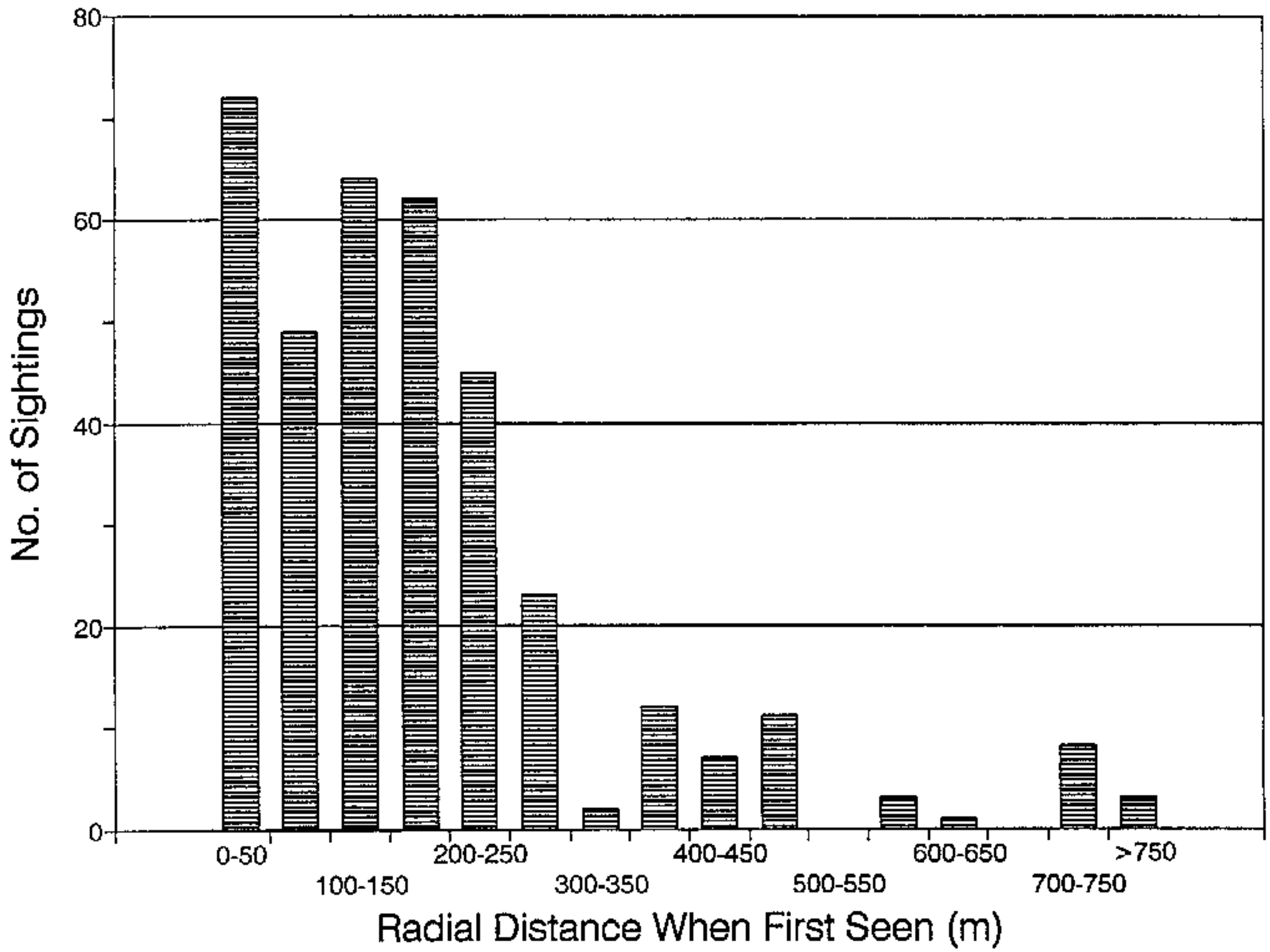

FIGURE 4.5. Numbers of seal sightings during daylight by 50 m radial distance intervals from the source vessel. Seals that were first seen in one distance interval were often seen subsequently at other distances, but only the first sighting is counted here.

The breakdown by species is presented in Table 4.2. That table also shows, for each category of seismic operations, the species breakdown as percentages of all identified seals seen. Of the 331 seals that were identified (78.4% of the total seals seen), almost 92% were ringed seals. Very few bearded seals (24; 7.3%) and even fewer spotted seals (3; 0.9%) were identified. One walrus and four polar bears also were seen (see Appendix 1). Observers on the source vessel did not see any whales.

Sighting Rates and Distances

Table 4.3 and Figure 4.6 summarize the data regarding the 421 seals that were observed in different seismic states and at different distances from the source vessel during daylight surveys. The six seismic states are no guns, single gun, partial array (2-7 guns), full array (8-11 guns), ramp-up, and seismic testing. Distances were categorized as <150 m, 150 to 250 m, and >250 m from the source vessel, corresponding to the safety zones identified in the IHA for seals. To compare appropriately the numbers of seals that were encountered during different seismic states, the data were standardized to numbers of seals observed per hour of daylight survey effort in each seismic state.

Distances from the source vessel were not determined for 20 seals. These seals are included in the "Total" bars on Figure 4.6. Consequently the "Total" bars sometimes show more seals than are represented in the three known distance categories. This is most evident with respect to the full array data (8-11 guns); distances were not determined for 17 seals in this seismic category (Table 4.3).

The largest numbers of seals were observed during full-array seismic, no-seismic, and single-gun seismic periods. Likewise, the largest numbers of hours of daylight observations were during those three seismic categories (Table 4.3). Consequently, the discussion that follows focuses on these categories. Less time was spent conducting partial-array and ramp-up seismic, and relatively few seals were observed during those conditions. No seals were observed during seismic testing—the least frequent category of operation (Table 4.3).

Numbers Seen With vs. Without Seismic.—The total numbers of seals seen during daylight periods were 164 under no-seismic conditions, 57 when a single airgun was in use, 17 when a partial array (2-7 airguns) was operating, 168 when the full array (8-11 airguns) was operating, and 15 during ramp-up. The breakdown by distance categories is given in Table 4.3 and is further described in §4.5, "Estimated Take". The one seal seen during periods of darkness was sighted within 150 m of the source vessel during full-array seismic. It is not included in the following discussion.

Overall, seals were observed at nearly identical rates during periods with no guns firing (0.63 seals/h), one gun firing (0.60/h), and a full array (0.63/h; Fig. 4.6). These were the three common seismic categories. Slightly more seals were seen per hour without seismic (0.63/h) than with all seismic categories combined (0.53/h). This difference was a result of the low sighting rate during the limited amount of seismic work with a partial array (Fig. 4.6).

TABLE 4.2. Numbers and species of seals observed from the source vessel in different seismic states, with percentages relative to the total of all identified seals in that seismic category. Only one of these seals, a ringed seal under full array, was observed during darkness. "Partial Array" = 2-7 guns; "Full Array" = 8-11 guns.

		NUMBERS OF SEALS									
		Identified		Ringed Seal		Bearded Seal		Spotted Seal		Unidentified Seal
SEISMIC STATE	Total	#	%	#	%	#	%	#	%	#
No Guns	164	136	82.9%	121	89.0%	15	11.0%	0	0.0%	28
Single Gun	57	47	82.5%	44	93.6%	3	6.4%	0	0.0%	10
Partial Array	17	12	70.6%	11	91.7%	0	0.0%	1	8.3%	5
Full Array	169	129	76.3%	121	93.8%	6	4.7%	2	1.6%	40
Ramp-Up	15	7	46.7%	7	100.0%	0	0.0%	0	0.0%	8
Seismic Testing	0									
TOTALS	422	331	78.4%	304	91.8%	24	7.3%	3	0.9%	91
Within safety radius*	160	133	83.1%	127	95.4%	5	3.8%	1	0.8%	27

* This includes all seals within 150 m of the source vessel during single gun seismic, and all seals within 250 m during partial- or full-array seismic (including ramp up). See Table 4.3 and Section 4.5 Estimated Take.

TABLE 4.3. Numbers of seals, and numbers of seals per hour of daylight observation, observed from the source vessel in different seismic states and at different distances. Only seals seen during daylight are included here.*
"Partial Array" = 2-7 guns; "Full Array" = 8-11 guns.

		NUMBERS OF SEALS								
	# Hours Daylight	Total*		<150 m		150-250 m		>250 m		Distance Not Determined
SEISMIC STATE	Observation	#	#/hr	#	#/hr	#	#/hr	#	#/hr	#
No Guns	262.3	164	0.63	97	0.37	40	0.15	25	0.10	2
Single Gun	95.3	57	0.60	32	0.34	18	0.19	7	0.07	0
Partial Array	72.1	17	0.24	7	0.10	4	0.06	6	0.08	0
Full Array	269.2	168	0.63	55	0.21	50	0.19	46	0.17	17
Ramp-Up	26.7	15	0.56	6	0.22	6	0.22	2	0.07	1
Seismic Testing	26.3	0	0.00							
TOTALS	751.9	421	0.56	197	0.26	118	0.16	86	0.11	20

* A total of 422 seals was seen; 421 during daylight plus one at night. The nighttime seal sighting is not included here.

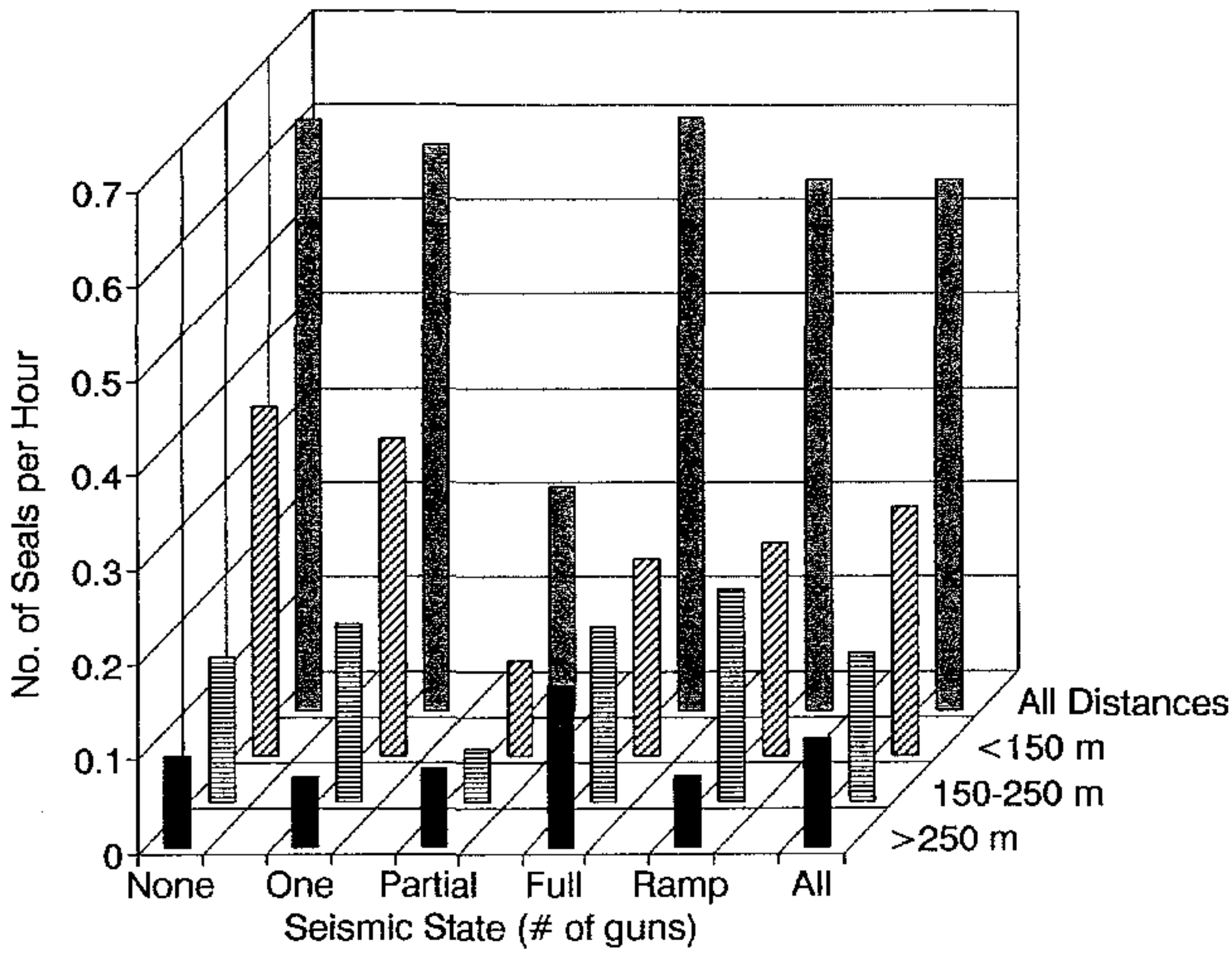

FIGURE 4.6 Numbers of seals observed from the source vessel, per hour of daylight observation, in different seismic states and at different distances from the source vessel. The "All Distances" category includes seals at known and undetermined distances; see Table 4.3 for details. None = no airguns; One = single airgun; Partial = 2-7 airguns; Full = 8-11 airguns; Ramp = ramp-up (increasing number of airguns over time).

Numbers vs. Distance, With vs. Without Seismic.—Did seismic state have any effect on the distances at which seals were first seen? If seals avoided the vessel during some or all types of airgun operations, the relative numbers seen in the various distance categories would be expected to differ among seismic states. Note that the areas under observation in the three distance categories are not equal, and that sightability decreases with increasing distance. Thus, comparisons of sighting rates in "seals per hour" must be done with caution, emphasizing relative sighting rates and distribution patterns rather than absolute numbers.

Within 150 m of the source vessel, where airgun noise was the strongest, seals were encountered most frequently during periods without seismic (0.37 seals/h). The number of seals seen per hour in the <150 m distance category was only slightly lower during single-gun seismic (0.34/h), but was notably lower during full-array seismic (0.21/h; Fig. 4.6). Conversely, the sighting rates in the >250 m category were lower with no seismic (0.10/h) or single-gun seismic (0.07/h) than with full array seismic (0.17/h; Fig. 4.6).

Although the overall sighting rate with full array seismic (0.63 seals/h) was similar to overall rates with no seismic (0.63/h) and single gun seismic (0.60), the pattern by distance category was not. With full (and partial) array seismic, sighting rates on a "seals per hour" basis were similar in the three distance categories. In contrast, with no seismic or single-gun seismic, sighting rates diminished with increasing distance (Fig. 4.6; Table 4.3). In other words, seals were encountered relatively more frequently at distances >250 m during full-array seismic.[3] Overall, the distance distributions of seals (Fig. 4.6; Table 4.3) and of seal sightings during single-gun seismic and no seismic were similar (Mann-Whitney U=4451, n= 56, 161 sightings, P>0.5). In contrast, the distribution of sighting distances during full-array seismic was very different than that for no seismic (U=8408, n=150, 161 sightings, P<0.001).

These results suggest that seals showed some tendency to avoid at least the zone closest to the boat (<150 m) during full-array seismic. The same was probably true during partial-array seismic, but the sample size was low. There was no such indication during single-gun seismic. The simplest explanation of the observations is that, as the seismic boat approached the seals while operating the full and probably the partial array, seals tended to move out of the <150 m distance zone and into the >250 m distance zone. However, they apparently did not move much beyond 250 m, as the observers rarely detected seals beyond 400-500 m, and the overall sighting rate was the same (0.63/h) with full-array seismic as with no seismic.

Overall, vessel-based observers saw seals at nearly identical rates regardless of whether no guns, a single gun, or 8-11 guns (full array) were firing. As would be expected, seals were seen most often close to the boat, and less often at greater distances. However, with full-array seismic, seals were encountered less frequently within 150 m of the source vessel and more frequently at distances between 250 m and the limits of vision, generally near 500 m for most seals. This suggests that, during operation of the full airgun array, some seals had

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[3] This would hold true even if all 17 seals seen at undetermined distances were actually in the <150 m category (55 + 17 = 72; 72/269.2 h = 0.27 seals/h; see Table 4.3).

a tendency to avoid the source vessel, possibly combined with a tendency to spend more time at the surface at the longer distances.

Distribution Around Source Boat, With vs. Without Seismic

The bearings of seal sightings around the source vessel under different seismic conditions, and overall, are shown in Table 4.4 and Figure 4.7. Positions were obtained for 238 of the 381 sightings made during daylight surveys. For the other 143 daylight sightings, bearing and/or radial distance were not recorded and thus locations could not be derived.

The recorded distributions in part reflect the data collection methods. Most sightings were recorded as being on lines radiating from the source vessel at 30-degree (occasionally 45°) intervals (Fig. 4.7). The bearing data were collected as "hours of the clock" relative to the vessel's bow. A seal seen 60° from the bow and to starboard was recorded as being at 2 o'clock. Seals on bearings from 45° to 75° to starboard were almost all recorded as being at 2 o'clock (i.e., most bearings were recorded by 30° category). Similarly (though less obviously in Figure 4.7), many radial distances, and especially the longer distances, also were grouped at the distances corresponding to the reticle markings on the binoculars. However, these measurements were made the same way for each seismic state and thus still allow meaningful comparisons.

Overall, the majority of initial sightings were made in front of, and to the sides of, the source vessel (Fig. 4.7D). Fewer initial sightings were made behind the bow of the source boat. This pattern reflects the fact that the marine mammal observers spent more time trying to detect seals that were ahead of the boat, as one of the observers' primary duties was to shut the airguns down when mammals about to enter the safety zone were sighted.

When no guns were firing, the sightings were distributed almost symmetrically around the source vessel, although the distance distributions on various bearings varied somewhat (Table 4.4, Fig. 4.7A). Overall, about 85% of the initial sightings when no guns were firing were to the front and sides of the source boat ("9 through 3 o'clock"). Nearly 14% were directly in front of the boat (12 o'clock); 26.5% were to the port front (10 to 11 o'clock); another 26.5% were to the starboard front (1 to 2 o'clock); and 9% and 10% were directly to the port and starboard sides respectively (9 and 3 o'clock). Fewer seals were sighted behind the source vessel (15% of sightings; Table 4.4).

The distribution of initial sightings under full-array seismic also was concentrated in front of and to the sides of the source vessel, and also was nearly symmetrical (Table 4.4, Fig. 4.7C). In comparison with the no-gun distribution, the percentage of the initial sightings made between 9 o'clock and 3 o'clock was only slightly greater with full-array seismic (89% vs. 85%; χ^2=0.38, df=1, P>0.5). During full-array seismic, there were slightly more initial sightings to starboard (1- through 5 o'clock) than to port (7- through 11 o'clock; 43.5% vs. 36.5%), but again the difference was not statistically significant (χ^2=0.53, df=1, P>0.25). The radial plots also show a greater dispersion in initial sighting distances during full-array periods than when no guns were firing (Fig. 4.7C vs. A), as shown previously.

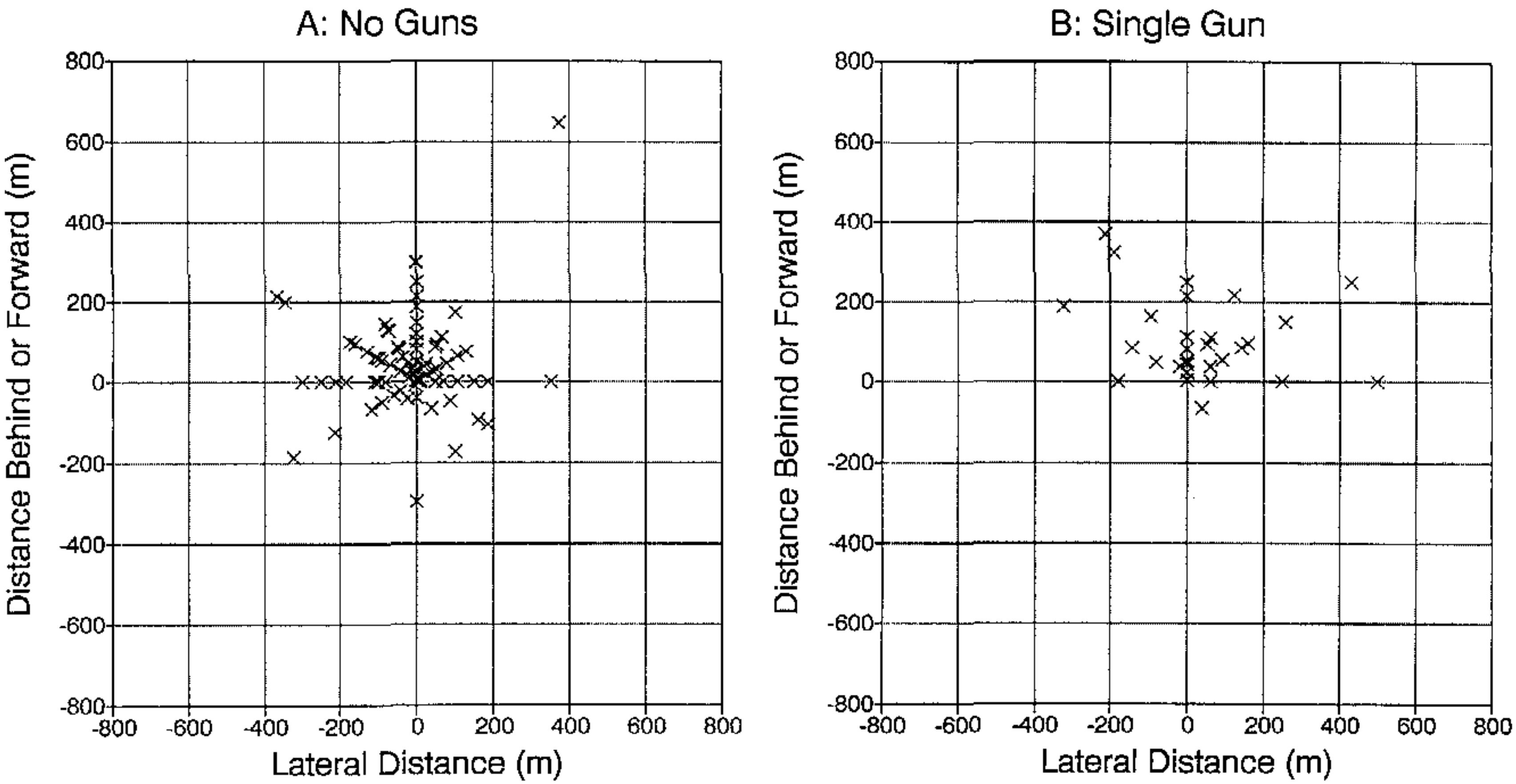


FIGURE 4.7. Distribution of the initial sightings of seals around the source vessel under different seismic conditions, and for all sightings. The seismic vessel is located at coordinates 0-0.

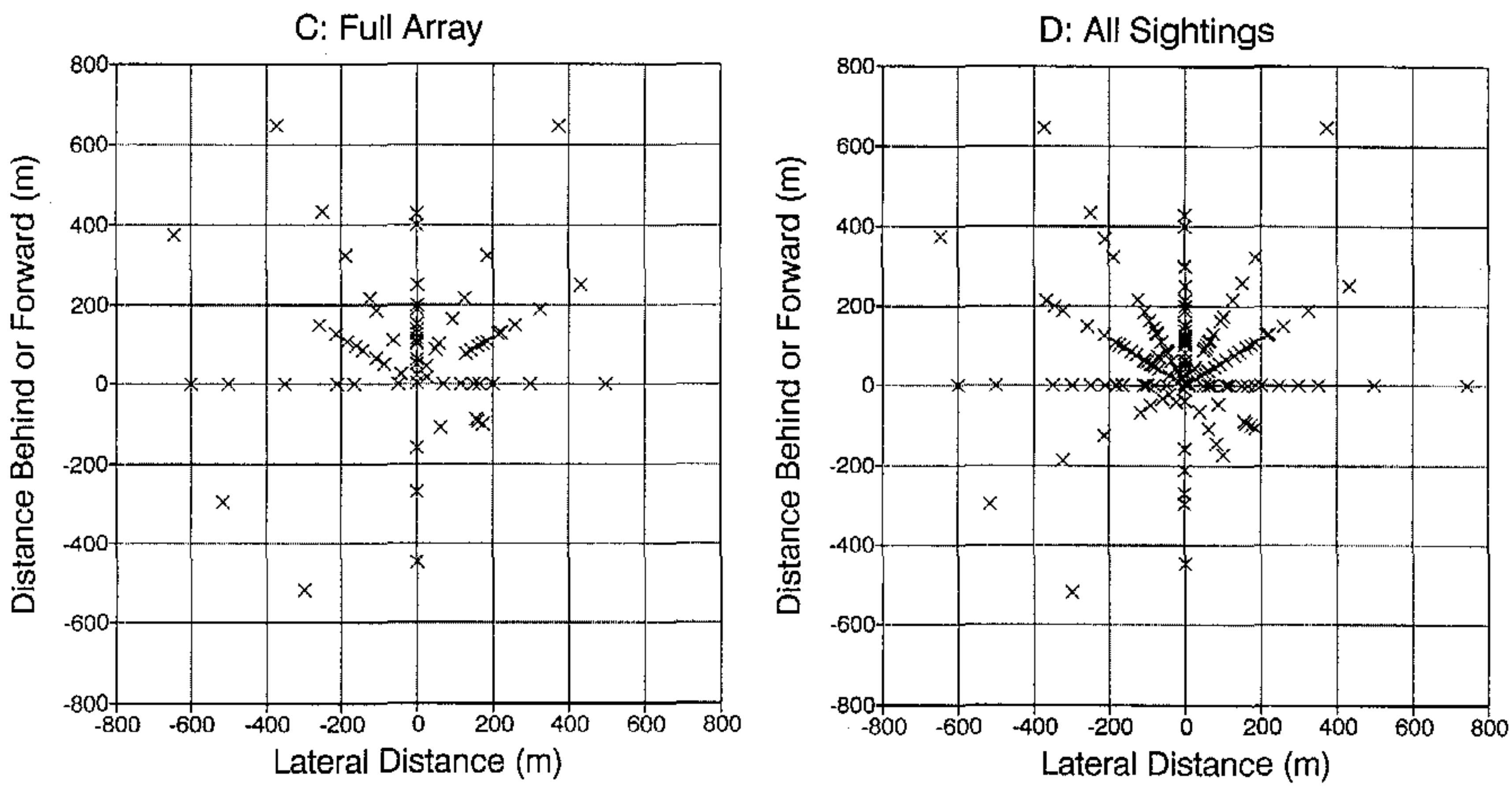


FIGURE 4.7. Continued.

Table 4.4. The distribution of the initial sightings of seals around the source vessel by clock face position relative to the bow,in different seismic states: A. Numbers of sightings, B. Percentages of sightings in each seismic state. "Partial Array" = 2-7 guns; "Full Array" = 8-11 guns.

A.		NUMBERS OF SIGHTINGS BY CLOCK FACE POSITION RELATIVE TO THE BOW*													
SEISMIC STATE	Total	7	8	9	10	10:30	11	12	1	1:30	2	3	4	5	6
No Guns	102	2	6	9	13	2	12	14	12	3	12	10	3	2	2
Single Gun	33	0	0	1	3	3	4	8	3	1	6	3	0	1	0
Partial Array	8	0	0	0	0	1	0	1	3	0	2	1	0	0	0
Full Array	85	1	1	7	13	1	8	14	10	2	13	8	3	1	3
Ramp-Up	10	0	1	1	0	0	2	2	1	1	0	0	0	2	0
Seismic Testing	0														
ALL SIGHTINGS	238	3	8	18	29	7	26	39	29	7	33	22	6	6	5

B.		PERCENTAGES OF SIGHTINGS BY CLOCK FACE POSITION RELATIVE TO THE BOW*													
SEISMIC STATE	Total	7	8	9	10	10:30	11	12	1	1:30	2	3	4	5	6
No Guns	102	2.0	5.9	8.8	12.7	2.0	11.8	13.7	11.8	2.9	11.8	9.8	2.9	2.0	2.0
Single Gun	33	0.0	0.0	3.0	9.1	9.1	12.1	24.2	9.1	3.0	18.2	9.1	0.0	3.0	0.0
Partial Array	8	0.0	0.0	0.0	0.0	12.5	0.0	12.5	37.5	0.0	25.0	12.5	0.0	0.0	0.0
Full Array	85	1.2	1.2	8.2	15.3	1.2	9.4	16.5	11.8	2.4	15.3	9.4	3.5	1.2	3.5
Ramp-Up	10	0.0	10.0	10.0	0.0	0.0	20.0	20.0	10.0	10.0	0.0	0.0	0.0	20.0	0.0
ALL SIGHTINGS	238	1.3	3.4	7.6	12.2	2.9	10.9	16.4	12.2	2.9	13.9	9.2	2.5	2.5	2.1

* 12 o'clock = straight ahead; 6 o'clock = directly behind the source vessel.

The distribution of initial sightings during single-gun seismic had a smaller sample size (33 sightings), but was also virtually symmetrical on the port and starboard sides. Almost all initial sightings (32 of 33) were to the front and sides (9 to 3 o'clock).

In summary, these data do not reveal any distinct differences in the bearings of initial seal sightings relative to the source vessel under different seismic conditions. During all conditions (no guns, full array and single gun), the distributions of initial sightings were nearly symmetrical with respect to the vessel's bow, and the majority of initial sightings were to the front and sides of the vessel. Sighting distances did vary under different seismic conditions, as discussed in previous subsections.

Behavior Observed From Source Boat

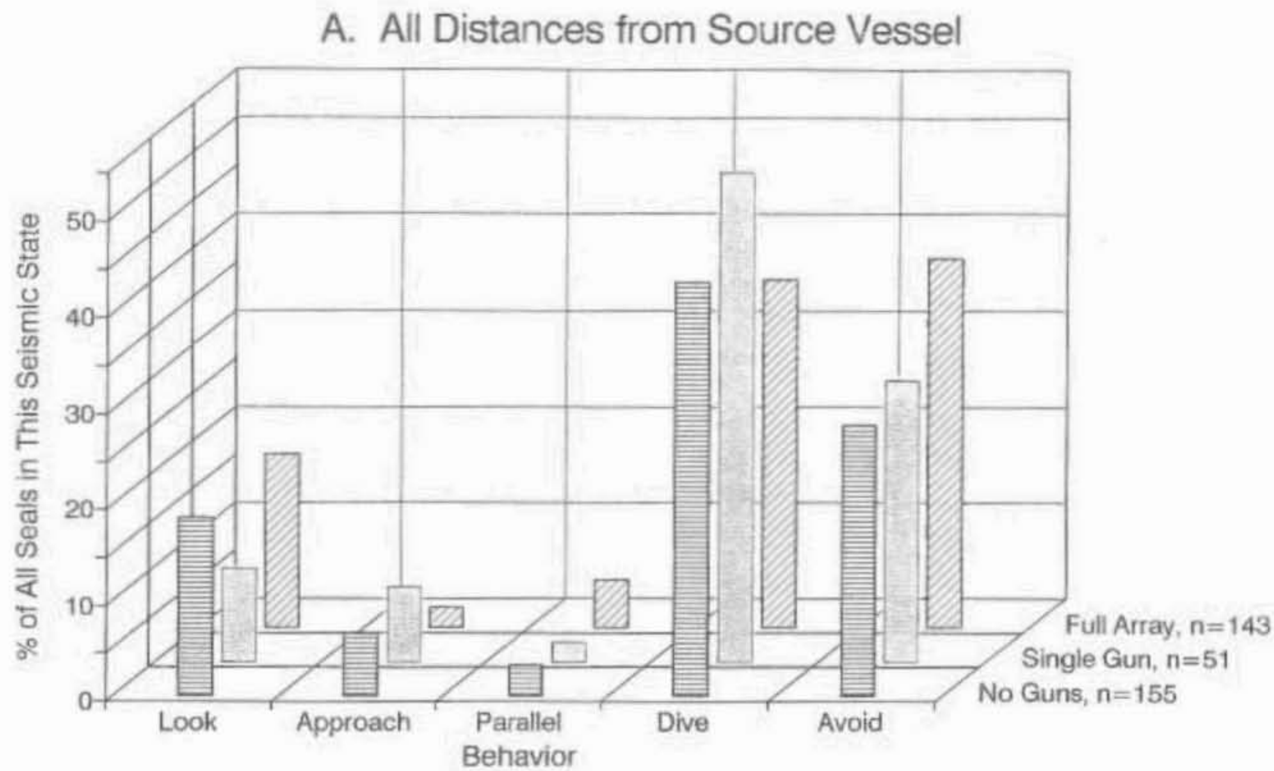
Figure 4.8 and Table 4.5 show the observed behaviors of seals during different seismic states and at different distances from the source vessel. The graph shows percentages of the total seals seen in a given seismic state that exhibited each behavior. For example, of all seals sighted when the full array was firing and for which a behavior was recorded, 18% "looked", 2% swam toward or "approached", 5% swam parallel to the boat's track, 36% dove, and 39% swam away or "avoided" (Table 4.5; Fig. 4.8A, hatched red bars).

Because the sample sizes were substantial only for the no gun, single gun, and full array (8-11 gun) categories, only these seismic states are discussed below. Also, seals are difficult to observe in the water, both because of their small size and because of their short surfacings. Consequently, behavioral observations were brief and often lacking in detail.

Behavior With vs. Without Seismic.—All five behaviors were seen during each of the three common seismic states: no-seismic, single gun, and full array (Fig. 4.8A). For each of those seismic states, the most commonly recorded behaviors were dive and swim away/avoid. The least common behavior was swimming parallel to the boat's track. Considering all distances together (Fig. 4.8A), the proportions of seals showing the various behaviors were generally similar during periods without seismic and with single-gun seismic. During full-array seismic, proportionally fewer seals dove and proportionally more swam away as compared with no seismic and single-gun seismic.

Behavior at Different Distances.—Within 150 m of the source vessel, similar (and high) percentages of seals dove and swam away regardless of the seismic state (Fig. 4.8B). Moderate percentages looked. Seals were observed to swim toward the boat more frequently when no guns were firing than during single-gun seismic, and no seals were observed to swim toward the seismic vessel during full-array seismic.

For seals at 150-250 m distance from the source vessel, diving and swimming away (avoidance) were again the most frequently observed behaviors (Fig. 4.8C). During full-array seismic, a lower percentage of seals dove and a higher percentage showed avoidance, as compared to the percentages without seismic or with one gun firing. A few seals "approach-



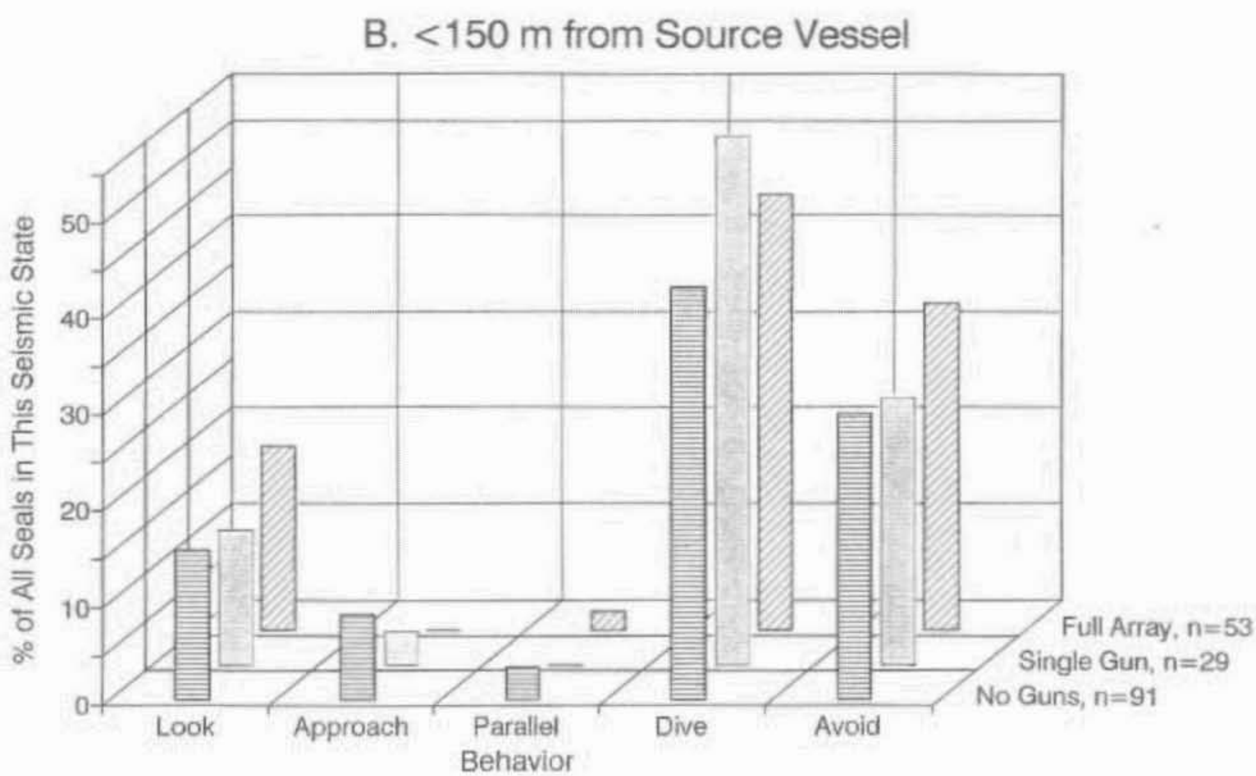
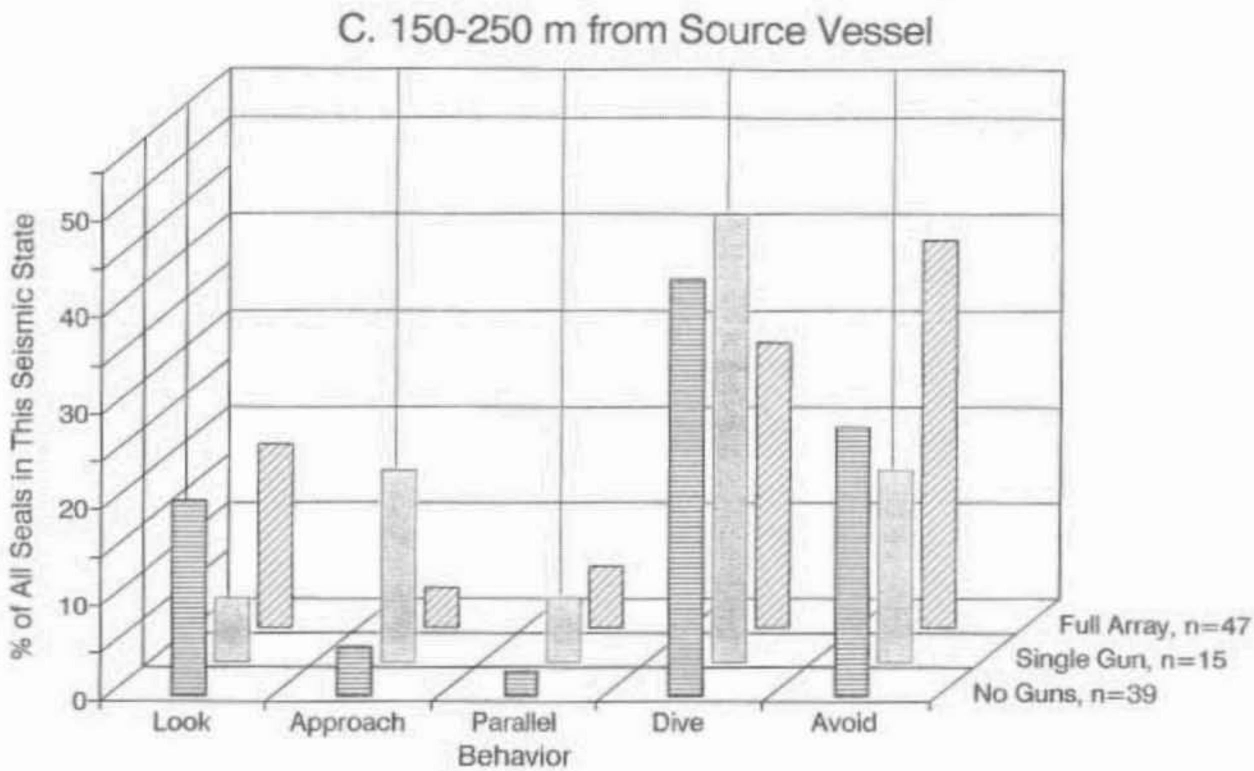


FIGURE 4.8. Observed behaviors of seals during different seismic states and at different distances from the source vessel. For each seismic state, the bars show the percentages of the seals that exhibited various behaviors. Table 4.5 shows corresponding numerical details and the few data from "partial array" and "ramp-up" periods.



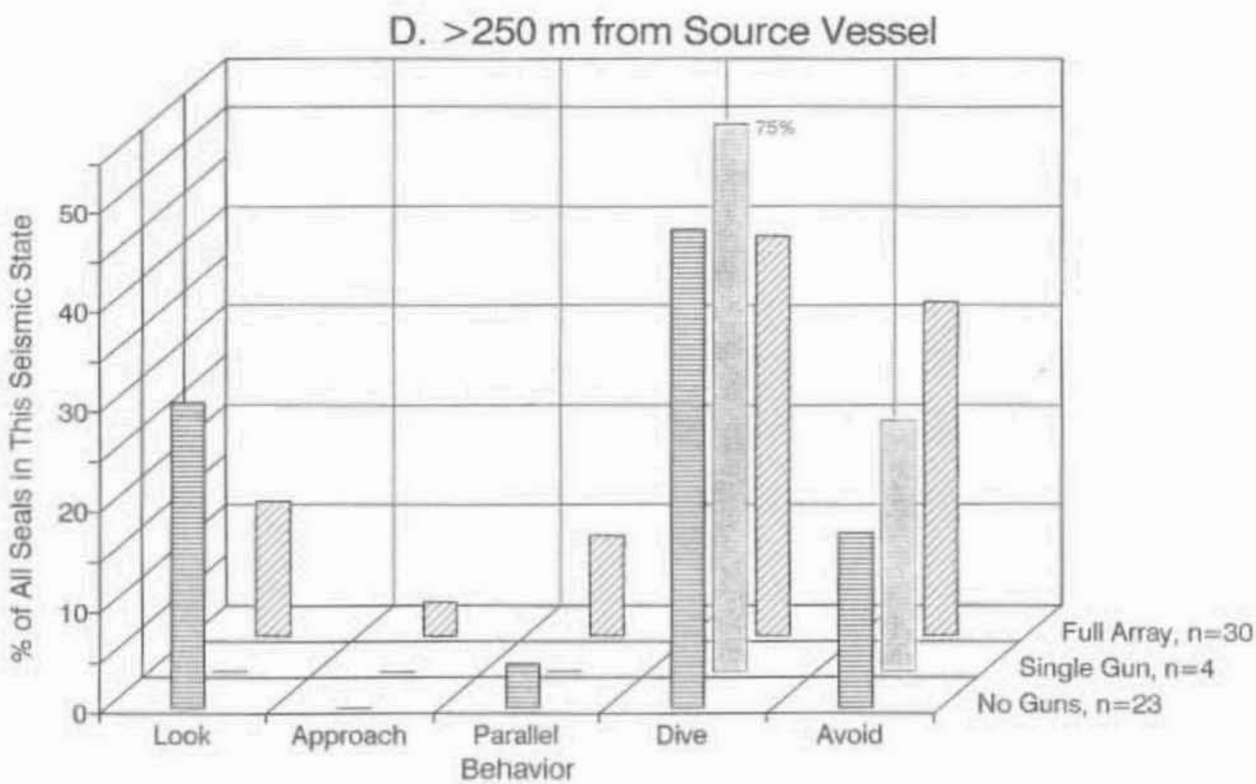


FIGURE 4.8. Continued.

TABLE 4.5. The observed behaviors of seals during different seismic states and at different distances from the source vessel, shown as the numbers and percentages of seals in each category. Percentages are of all seals for which a behavior was recorded in that seismic state (subtotal rows), that exhibited a particular behavior. "Partial Array" = 2-7 guns; "Full Array" = 8-11 guns.

	NUMBERS AND PERCENTAGES OF SEALS								
	All Distances		<150 m		150-250 m		>250 m		Distance Not Determined
BEHAVIORS	#	%	#	%	#	%	#	%	#
NO GUNS									
Look	29	18.7	14	15.4	8	20.5	7	30.4	0
Approach	10	6.5	8	8.8	2	5.1	0	0.0	0
Parallel	5	3.2	3	3.3	1	2.6	1	4.3	0
Dive	67	43.2	39	42.9	17	43.6	11	47.8	0
Avoid	44	28.4	27	29.7	11	28.2	4	17.4	2
Subtotal	155	100.0	91	100.0	39	100.0	23	100.0	2
Unknown	9		6		1		2		0
Total	164		97		40		25		2
SINGLE GUN									
Look	5	9.8	4	13.8	1	6.7	0	0.0	0
Approach	4	7.8	1	3.4	3	20.0	0	0.0	0
Parallel	1	2.0	0	0.0	1	6.7	0	0.0	0
Dive	26	51.0	16	55.2	7	46.7	3	75.0	0
Avoid	15	29.4	8	27.6	3	20.0	1	25.0	3
Subtotal	51	100.0	29	100.0	15	100.0	4	100.0	3
Unknown	6		3		3		0		0
Total	57		32		18		4		3
PARTIAL ARRAY									
Look	3	23.1	1	16.7	1	50.0	1	20.0	0
Approach	3	23.1	2	33.3	0	0.0	1	20.0	0
Parallel	0	0.0	0	0.0	0	0.0	0	0.0	0
Dive	4	30.8	3	50.0	1	50.0	0	0.0	0
Avoid	3	23.1	0	0.0	0	0.0	3	60.0	0
Subtotal	13	100.0	6	100.0	2	100.0	5	100.0	0
Unknown	4		1		2		1		0
Total	17		7		4		6		0
FULL ARRAY									
Look	26	18.2	10	18.9	9	19.1	4	13.3	3
Approach	3	2.1	0	0.0	2	4.3	1	3.3	0
Parallel	7	4.9	1	1.9	3	6.4	3	10.0	0
Dive	52	36.4	24	45.3	14	29.8	12	40.0	2
Avoid	55	38.5	18	34.0	19	40.4	10	33.3	8
Subtotal	143	100.0	53	100.0	47	100.0	30	100.0	13
Unknown	26		3		3		16		4
Total	169		56		50		46		17
RAMP UP									
Look	0	0.0	0	0.0	0	0.0	0	0.0	0
Approach	2	18.2	2	40.0	0	0.0	0	0.0	0
Parallel	0	0.0	0	0.0	0	0.0	0	0.0	0
Dive	7	63.6	2	40.0	3	75.0	2	100.0	0
Avoid	2	18.2	1	20.0	1	25.0	0	0.0	0
Subtotal	11	100.0	5	100.0	4	100.0	2	100.0	0
Unknown	4		1		2		0		1
Total	15		6		6		2		1
TOTAL # SEALS	422		198		118		83		23
Behavior Known	373		184		107		64		18
Behavior Unknown	49		14		11		19		5

ed" during each seismic state. Few seals were seen at 150-250 m with single-gun seismic.

Fewer seals were observed at distances >250 m (Fig. 4.8D; Table 4.5). Some behaviors were not observed during certain seismic states, possibly as a consequence of the lower sample sizes. During full-array seismic, proportionally more seals swam away (avoided) and fewer looked than during the no-guns condition.

For the two most common behaviors, diving and swimming away, distance-related effects were not clear. With full-array seismic, the frequency of diving was less >250 m away than at <150 m, but was least at 150-250 m. The frequency of swimming away was about the same >250 m away as at <150 m, but was higher at 150-250 m. During full-array seismic, most seals within 250 m of the source vessel dove or swam away, with diving being most common inside 150 m and swimming away being most common at 150-250 m.

The distance-dependence of some less-common behaviors may also have been related to seismic state. However, caution is needed: some reactions may be more difficult to detect at long distances, and some sample sizes were small. No seals within 150 m were observed to swim toward ("approach") the source vessel during full-array seismic, but small percentages did approach when 150-250 m and >250 m away. With increasing distances, increasing percentages of seals "looked" when no guns were firing, whereas the percentages looking decreased with distance during single-gun and full-array seismic.

Received levels of seismic pulses are reduced at and near the surface relative to greater depths (Greene and Richardson 1988). It is possible that seals staying at the surface are reducing their exposure to the underwater seismic noise. Seals engaged in "looking" remained nearly stationary at the surface. Overall, "looking" was as frequent during full-array seismic as when no guns were firing, but at >250 m it was more common when no guns were firing than during full-array seismic. Overall, diving was less commonly seen with full-array seismic than without seismic, as expected if seals were tending not to dive to depths where sound exposure would be higher. However, this difference was largely a result of a reduced frequency of diving at the longer distances, not in the closest distance category (<150 m). This pattern is not consistent with the idea that seals may tend not to dive when sound levels below the surface are highest.

Swimming away (avoidance) was more frequent overall, and in all distance categories, during full-array seismic than when no guns were firing. However, the increased frequency was most noticeable at longer distances and less so at <150 m, contrary to our expectation.

4.5 Estimated Take

It is difficult to estimate the take of seals accurately for several reasons. (1) The relationship between the number of seals observed and the number actually present is uncertain. (2) The most appropriate criteria for take are uncertain. (3) The distance out to which the received sound level exceeds any given criterion like 190 dB or 160 dB re 1 µPa is variable, depending on water depth and probably on airgun depth and aspect (Chapter 3).

This section considers both the 190 and the 160 dB criteria. Also, it considers both direct observations of seals and indirect estimates based on calculated seal density. It does not attempt to include any estimate of the numbers of seals disturbed by vessels assisting with the seismic operations but not firing airguns.

In this section we assume that the received rms pulse level from the airgun array was 190 dB re 1 µPa or more at distances up to 250 m from the airgun array. This 250 m figure was determined during preliminary analyses of transmission loss tests conducted prior to 30 August 1996. Further analyses of these data have indicated that the 190 dB radius around the full array of 11 airguns was sometimes as high as 257 m, but more commonly was less than 250 m (Chapter 3, PHYSICAL ACOUSTICS MEASUREMENTS). We continue to use 250 m as the nominal 190 dB radius as called for by the IHA; this probably results in some overestimation of the number of seals exposed to an rms pulse level of 190 dB re 1 µPa.

When a single airgun was in use, the safety radius was defined in the field as 150 m. This was recognized as being an overestimate of the 190 dB radius. However, specific estimates of the actual received levels at various distances from a single airgun were not available until after the field program ended. Subsequent analysis has shown that the actual radius for 190 dB re 1 µPa rms pulse level was only a few meters (see Chapter 3). However, the number of seals seen within 150 m during operation of a single airgun is reported.

It should be noted that pulsed sounds can be measured in different ways, and the results depend on the measurement method. The rms pulse level (averaged over the effective duration of the pulse), as used in this project, is consistent with the methods used in previous studies of marine mammal reactions to seismic pulses. However, levels measured in this way are ~10 dB lower than the peak levels typically reported by geophysicists (see Chapter 3).

Direct Observation

Two hundred and fifty-seven seals were seen during seismic activity conducted during daylight periods (Table 4.3). Of these, 100 were seen within 150 m of the source vessel and 78 were at 150-250 m from the vessel. Of the 178 seals seen within 250 m of the vessel, 105 seals were seen during use of a "full array" (8-11 airguns), 11 seals with a "partial array" (2-7 guns), and 12 seals during "ramp up". The remaining 50 seals seen within 250 m were observed during operations with a single airgun; of those, 32 seals were seen within 150 m and 18 seals at 150-250 m.

Seals Seen Within Safety Zones During Daytime.—For the purposes of this discussion, it is assumed that all seals within 150 m of the source vessel during single-gun seismic and all seals within 250 m during partial- or full-array seismic (including ramp up) were within the safety zones defined in the IHA. Seals seen in the 150-250 m zone around the operating airgun array prior to 30 August are counted as being within the safety zone even though the safety zone was not officially expanded from 150 m to 250 m until 30 August.

In total, 160 seals were seen in these situations during daylight hours while seismic operations were underway (Table 4.3). Observations were conducted during all daylight hours while seismic operations were underway. The breakdown by species was 127 ringed seals, 5 bearded seals, 1 spotted seal, and 27 unidentified seals (Table 4.2). Of these 160 seals, 105 were seen within 250 m during use of a "full array" (8-11 airguns). Of the remaining 55 seals, 32 were seen within 150 m during single-airgun operations, and 23 were seen within 250 m during "partial array" and "ramp up" operations. Many of those 55 seals would not have been exposed to rms pulse levels ≥190 dB re 1 μPa.

Allowance for Seals Missed at Night.—Only one seal was seen from the source vessel during darkness. Seals undoubtedly were present during seismic activity in darkness, so an allowance should be made for seals that were present but not seen in these conditions. This number was derived by assuming that the rates at which seals were encountered during darkness were the same as those during daylight. For each type of seismic activity, the number of hours of operations conducted in darkness was multiplied by the corresponding sighting rate during daylight. For example, there was a total of 9.9 hours of single-gun seismic during darkness (Table 4.1). During daytime, seals were encountered within 150 m of the source vessel during single-gun seismic at the rate of 0.34 seals per hour (Table 4.3). This results in an estimate of about 3.4 seals (9.9 h x 0.34 seals/h) that were present but not seen during darkness when a single gun was firing.

Similar calculations were made for the other seismic categories by applying the sighting rates for seals within 250 m of the source vessel during daytime (from Table 4.3) to the corresponding numbers of hours of nighttime operations (from Table 4.1). The resulting estimated numbers of seals within 250 m during seismic operations at night are 2.3 seals during partial array operations, 25.4 seals during full array operations, and 2.1 seals during ramp-up.

The sum of these estimates, including the single-gun estimate, is about 33 seals. This represents the number of seals expected to occur within the 150 m radius during single-gun operations at night and within the 250 m radius during other seismic operations at night. Only one seal was seen at night.

Thus, an estimate of the overall number of seal takes, based on the number of seals exposed to seismic pulses within the 250 m and 150 m safety zones, can be obtained by adding the estimated 33 seals present there during nighttime operations to the 160 seals seen during daylight periods. This represents the estimated number of seals that would have been visible within the defined safety zones if all seismic operations had been conducted during daylight. Assuming that the species breakdown of the seals present at night was the same as that of seals identified within the safety zones during daylight seismic work (Table 4.2), the 193 seal "takes" would consist of 184 takes of ringed seals, 7 of bearded seals, and 2 of spotted seals.

Strong Behavioral Reactions Beyond Safety Zones.—In addition to the numbers of takes quoted above, it would be reasonable to include as "taken" any additional seals beyond the 150 m (single-gun) or 250 m (multiple-gun) radii that showed strong behavioral reactions.

Only the seals that were seen beyond the 250 m radius and that showed an avoidance reaction (swimming away) were included in this category. This comprised 14 seals seen during daylight surveys and an estimated three seals during surveys in darkness. The number of seals estimated to have shown an avoidance reaction during darkness was derived by assuming that this behavior occurred at the same rate during darkness as during daylight. The 14 seals seen in this behavioral category during daylight occurred during single-gun seismic (1 seal), partial-array seismic (3 seals), and full-array seismic (10 seals).

If these 17 seals (14 seen in daylight, plus 3 estimated for darkness) are added to the preceding estimates of take (160 seen during daylight periods within 150 m or 250 m; 33 more estimated to be present at night), the total estimated number of "takes by harassment" is 210. Some of these probably involved repeated takes of the same seal, given the proximity of adjacent seismic lines and various overlaps in seismic lines. Assuming the same percentage breakdown by species as observed directly within the safety radii (Table 4.2), these 210 seal takes would include 201 ringed seal takes, 8 bearded seal takes, and 1 spotted seal take.

Indirect Estimates Based on Seal Density

Estimating Density.—An estimate of the average density of seals in the area of seismic exploration during the 1996 open water season was derived by first determining an effective transect width within which it reasonably could be assumed that most seals at the surface were detected. This was done by calculating the lateral distance of each seal sighting from the vessel's trackline. This calculation was based on each seal's radial distance and bearing (relative to the bow) when the seal was first seen (sine of the bearing angle relative to bow x radial distance).

Figure 4.9 shows the number of sightings by 50 m categories of lateral distance. It is apparent that sightability was progressively lower in all lateral distance categories beyond 50 m than at lateral distances 0-50 m. The observed rate of fall-off in sightability with increasing lateral distance was very similar to that shown by Leopold et al. (1997) in a vessel survey of harbor seals. Thus, seal density in the area was estimated based on the number of individual seals seen in the 100-m strip centered on the vessel's trackline. To estimate seal density in the area, we tabulated the number of individual seals recorded as being within this 100-m strip (lateral distances 0-50 m) when no airguns were firing.[4] However, lateral distance was determinable for only 118 of the 164 seals sighted when the airguns

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[4] The sighting rate of seals within a lateral distance of 50 m was higher when no guns were firing than when guns were operating—a further indication that some seals showed avoidance of the source vessel when airguns were in use.

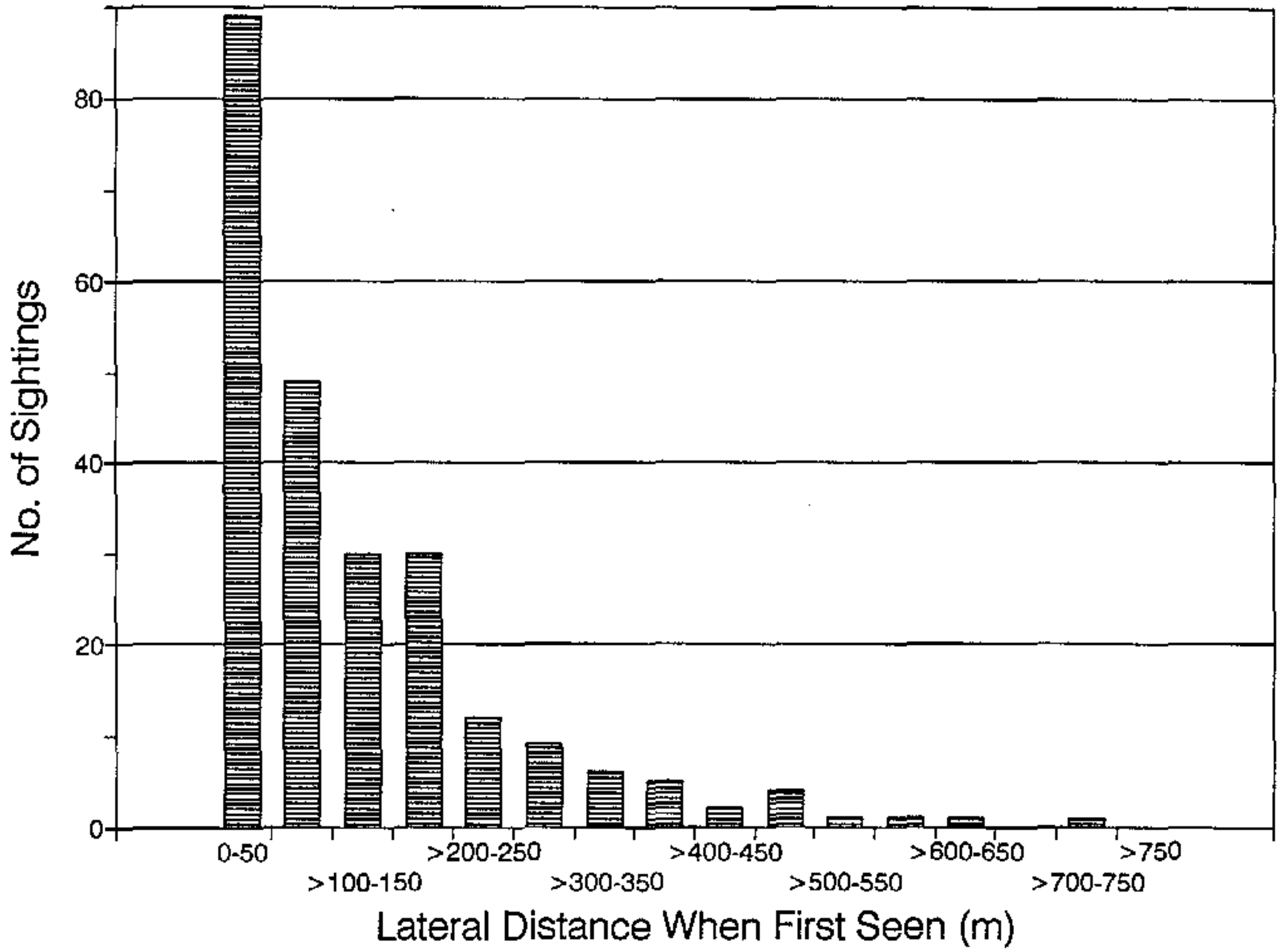

FIGURE 4.9. Numbers of seal sightings during daylight by 50 m lateral distance intervals from the source vessel's track. Lateral distance was determined from the seal's location when it was first seen.

were not firing. For the other seals, bearing and/or radial distance were not recorded. To allow for them, the number of seals recorded as being within the 100 m strip when no airguns were firing (47) was multiplied by 164/118, resulting in an overall estimate of 65 seals seen within the 100 m strip when no airguns were firing. This estimate assumes that the lateral distance distributions were the same for the seals whose lateral distances were and were not recorded.

The exact number of kilometers of survey during times without airgun operations was estimated from the average vessel speed and from the number of hours of observations without airgun operations. A total of 2946 km of production seismic was shot in 355 hours (8.3 km/h). A total of 834 km of OBRL was shot in 98 hours (8.5 km/h). We assume an average speed of 8.4 km/h during the times without airgun operations. It was the observers' impression that average speed during observation periods without airgun operations was similar to that with airgun operations.

During daylight, an estimated 65 seals were observed within the 100 m transect width during 262.3 h of observations (Table 4.1) when no guns were firing, and thus along about 2203 km of vessel trackline (262.3 h x 8.4 km/h). The area thus effectively surveyed was 220.3 km^2, and the observed seal density was about 0.30 seals/km^2. This estimate is not affected by the fall-off in sightability beyond 50 m, as it is based only on sightings within 50 m of the vessel's trackline. However, it does not allow for any seals that were not visible at the surface as the vessel passed close to their locations.

Estimated Number of "Takes" Within Safety Radii.—Single-airgun operations during BPXA's 1996 seismic program totaled about 883.7 km in length, based on 105.2 h of single-gun operations at 8.4 km/h (Table 4.1). Assuming a safety radius of 150 m, an area of ~265.1 km^2 was within this single-airgun safety radius at some time during the season (883.7 km x 300 m). Likewise, airgun array operations totaled ~3786.7 km, based on 450.8 h of full array, partial array, and ramp-up operations at 8.4 km/h (Table 4.1). Assuming a safety radius of 250 m, an area of ~1893.3 km^2 was within this 250 m safety radius at some time during the season (3786.7 km x 500 m). Thus a combined total area of 2158.4 km^2 was within the 150 m or 250 m safety radius at one or more times during the season.

Based on the estimated density value of 0.30 seals/km^2, about 648 seal takes are estimated to have occurred during BPXA's 1996 open water seismic operation. Assuming that the percentages by species were the same as above (see Table 4.2), the 648 takes involved 618 takes of ringed seals, 25 takes of bearded seals, and 5 takes of spotted seals.

Production source lines were only 333 m apart (Fig. 2.1 in §2.2), so the 500-m-wide strips centered on adjacent source lines overlapped. Thus, some areas were within 250 m of the operating seismic array on more than one occasion during the season. Also, the single airgun OBRL lines were perpendicular to the production source lines, and the 300-m-wide strips around the OBRL lines covered the same area as was covered at earlier or later times by the airgun array. Therefore, some of the "takes" estimated above, including most if not all of the takes during single-airgun OBRL work, presumably involved the same seals as "taken" at other times by operations with the airgun array.

Estimated Numbers of Seals "Taken" Within Safety Radii.—The number of individual seals "taken" would be lower than the number of "takes", as many of the seals "taken" were presumably within the safety radius around the operating vessel on more than one occasion during the 1996 open water season. The number of seals taken one or more times can be estimated based on the average density of seals derived above (0.30 seals/km^2) and on the total water area where sound levels exceeded the appropriate criterion levels.

To estimate the total number of seals that were potentially within 250 m of the operating seismic array at one or more times during the season, the area where BPXA conducted seismic surveys in 1996 was first defined. This was done by drawing a perimeter around the entire area within which production seismic was shot during 1996. Then we added a 250 m buffer, but excluded waters south of the barrier islands. The actual seismic area and the buffered area were calculated by MapInfo based on digital maps of the source vessel movements (Fig. 2.2, 2.4 and the additional areas surveyed before 15 August). The actual seismic area totaled 581 km^2, and the total area including the 250 m buffer was 629 km^2.

Assuming a density of 0.30 seals/km^2, the total number of seals potentially within the 250 m safety radius of the operating array on one or more occasions would be about 189 seals. As the estimated number of seal "takes" was 648 this means that an average seal within the operating area was within the safety radius on 3.4 occasions. This is a reasonable value for the estimated average number of "takes" per seal, given the overlap between adjacent "patches"[5], the overlapping safety zones as the source vessel moved along adjacent shot lines, and the overlap between production seismic lines and the transverse OBRL lines.

Estimated Numbers Exposed to 160 dB Received Level.—The IHA did not include a formal requirement to estimate the number of seals exposed at levels other than ≥190 dB re 1 μPa. However, the monitoring plan called for an estimate of the number exposed to received levels of ≥160 dB re 1 μPa. This section derives that estimate.

For the purposes of this discussion, it is assumed that all seals within 4900 m of the source vessel during full-array seismic (including some ramp up) may have been exposed to sound pulses with rms received levels as high as 160 dB re 1 μPa (see CHAPTER 3). The radius would be somewhat less when the full array was operating in shallower parts of the survey area or when a partial array was in use, and it would be much less with a single airgun. Because the source lines were spaced only 330 m apart, a seal at a given location would be repeatedly exposed to sounds exceeding 160 dB as the vessel moved back and forth along a series of adjacent lines.

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[5] The source vessel traveled well into the adjoining patches while surveying each patch (see Fig. 2.1).

The total area within which sound levels were ≥160 dB re 1 µPa at any time during the season was estimated as the area of the "patches" plus a 4900 m buffer. This was done with MapInfo as described above, but using a 4900 m buffer rather than a 250 m buffer. Again, we excluded waters south of the barrier islands. The total area thus enclosed is 1348 km^2, consisting of the 581 km^2 of actual survey patches plus 767 km^2 of buffer.

Based on the estimated density of 0.30 seals/km^2, approximately 404 seals were exposed to sound pulses with rms received levels as high as 160 dB re 1 µPa. Assuming that the percentages by species were the same as above (see Table 4.2), the 404 seals consisted of 386 ringed seals, 15 bearded seals, and 3 spotted seals.

Shutdown of Airguns

In almost all instances when airguns were firing and seals were seen within the safety zones designated by NMFS, the airguns were shut off within a few seconds (see Chapter 2, SEISMIC PROGRAM DESCRIBED). During BPXA's 1996 seismic program, the airgun(s) were shut down because of seals within or about to enter the safety zone on 135 occasions. The interval between seismic impulses was 15 to 18 s during partial- and full-array seismic and 8 s during single-gun seismic. In the majority of cases, the airguns were shut off during the interval between the first sighting of the seal and the next scheduled airgun shot. Very few seals within the safety zone were exposed to more than one shot after they were first sighted.

On 30 August, the safety zone for operations with an airgun array (2-11 guns) was expanded from 150 m to 250 m. Before that date, some of the seals that were 150-250 m from the source boat may have been exposed to sound pulses at received levels as high as about 195 dB (see Chapter 3). The airguns were not shut down for these seals because they were beyond the safety zone of 150 m that was in effect for airgun array operations up to 30 August. Thirty-nine seals were seen under these circumstances—26 ringed seals, 4 bearded seals, 1 spotted seal, and 8 unidentified seals. A seal at a given location within the 250 m radius would be exposed to only a small number of pulses as the seismic boat moved past shooting once every 44 m. It is unlikely that exposure of seals to a few brief sound pulses at levels of 190-195 dB re 1 µPa would have significant effects on seal hearing. Also, not all seals within the 150-250 m zone would receive sounds exceeding 190 dB re 1 µPa: the received level at 250 m distance was often less than 190 dB (Chapter 3), and seals remaining near the surface would be exposed to lower received levels because of the pressure-release-at-surface effect.

Summary of Take Estimates

The two approaches discussed above—direct observation and indirect estimate—include estimates of "takes" and of "seals taken". Estimates of "takes" attempt to count each seal every time that it occurred within the safety radius during periods of airgun operations. The estimated number of "seals taken", on the other hand, counts each individual seal once regardless of the number of times it was strongly ensonified. Seals that may have been disturbed by vessels not operating airguns are not specifically considered in these estimates.

The direct-observation method estimates "takes". Our overall estimate of "takes" with this method was a total of 210 seals, based on sightings of 160 seals within the safety radius, an allowance of 33 for seals present within the safety radius at night, and allowance for an additional 17 seals exhibiting strong reactions at distances beyond the safety radius. However, this method presumably underestimates the total number of "takes" because, even in daytime, seals can be present within 150 and especially 250 m of the trackline without being detectable (*cf.* Fig. 4.8). It should be noted, however, that there is also an element of overestimation, as the 150 m safety radius applied for single-airgun operations greatly exceeded the actual 190 dB radius for a single airgun. The 250 m radius applied for airgun array operations sometimes also exceeded the actual 190 dB radius (Chapter 3).

Indirect procedures were used to estimate both the number of "takes" and the number of "seals taken", assuming that seals within the safety radius of the operating airgun(s) are taken. The estimated number of takes (648) was greater than the estimated number of seals taken (189) because many individual seals were taken more than once as the survey vessel moved back and forth on overlapping or similar lines through the study area. Both of these figures would be underestimates if the density of seals was underestimated. Seal density (0.30 seals/km^2) was estimated based on numbers seen within a lateral distance of 50 m from the vessel trackline during times without airgun operations. In all likelihood, not all seals present within 50 m of the trackline were seen, but the proportion missed is not known.

Indirect procedures were also used to estimate the number of seals exposed to seismic pulses at received levels ≥160 dB re 1 μPa (404 seals). This is the estimated number of seals inside, or within 4.9 km of the edges of, the area of seismic operations. The IHA does not consider the 160 dB level to be a criterion of "take", so the estimated 404 seals exposed to seismic sounds with rms pulse levels ≥160 dB re 1 μPa is not an estimate of take in the context of the IHA. This figure could be overestimated as the received levels of seismic pulses often dropped below 160 dB at distances less than 4.9 km. However, it also could be underestimated because actual seal density may be higher than the 0.30 seals/km^2 observed within 50 m of the trackline at times without airgun operations.

The following summarizes the above numbers:

Direct Observation:		Indirect Estimate:	
Seen within safety zone =	160	"Takes" =	648
Allowance for night =	33	"No. taken" =	189
Strong reaction =	17	"160 dB" =	404
Total takes =	210		

All of these estimates are approximations, of varying reliability, mainly of the number of seals exposed to various received sound levels. ▸ Both the direct and the indirect estimates include allowance for seals missed at night, assuming that the encounter rate at night was similar to that during daytime. ▸ The indirect estimates are more realistic because they are based on numbers of seals seen within 50 m of the seismic boat, extrapolated to include the full area potentially affected. In contrast, the direct estimates are biased downward by the pronounced decrease in sightability at distances beyond 50 m. ▸ All methods were limited by the fact that an unknown proportion of the seals present within 50 m of the vessel were missed because they were below the surface as the vessel approached or were at the surface but missed by the observer.

With only one observer on watch at most times, and no specific data on the proportion of time when seals were visible at the surface, we have no way to estimate the proportion of seals present within 50 m of the trackline but missed. Leopold et al. (1997) suggested that a high proportion of the harbor seals close to their tracklines may have been detected. They based this interpretation on an apparent tendency for the harbor seals to surface as the survey vessel approached. It is not known whether the ringed and bearded seals observed here behaved in that way.

4.6 Effect on Accessibility to Hunters

The 1996 seismic operations apparently caused small scale displacement of some seals, as indicated by the lower sighting rates within 150 m of the source vessel during airgun array operations. However, the overall sighting rates for seals seen within a few hundred meters of the source vessel were almost identical during periods with no airguns, one airgun, and a "full array" of 8-11 airguns (Fig. 4.6). Thus, there was no indication that the seismic operation caused displacement of seals on a scale that could affect accessibility to hunters.

Hunters are also concerned that marine mammals exposed to industrial noise may become more "skittish" or otherwise difficult to harvest even if they are not physically displaced. We collected no specific information on "skittishness" of seals exposed to seismic pulses. However, there were indications that the proportional occurrence of various behavioral patterns were different among seals exposed to sounds from the airgun array. Seals exposed to seismic pulses were less likely to dive, and more likely either to swim away (avoid) or to exhibit no obvious behavior (Fig. 4.8A). There was some indication that subtle behavioral effects may have occurred amongst the most distant category of seals visible from the seismic vessel (Fig. 4.8D), which were mainly at distances of 250-500 m, as well as at distances <250 m. Whether these subtle behavioral effects would reduce, increase or have no effect on accessibility of seals to hunters is not known.

Hunters from Nuiqsut hunt for ringed and bearded seals at various times of year, including the open water season. However, insofar as we are aware, no seal hunting was taking place within or near the area of seismic operations during BPXA's 1996 open-water seismic program. The most important seal hunting area for Nuiqsut hunters is off the Colville delta, extending as east as far as Pingok Island (149°40'W). Most of BPXA's 1996 seismic program was well to the east of this region. The seismic work approached Pingok Island only during mid-September when the main focus of the Nuiqsut hunters was on bowhead whales, not seals. The Nuiqsut hunters have not mentioned to BPXA or LGL any situations when they felt that BPXA's 1996 seismic program was interfering with seal hunting.

In summary, seals did not appear to be displaced far enough from the seismic operation to affect accessibility to hunters, although some local displacement was detected within 250 m of the seismic array. There were some changes in proportional occurrence of various behaviors, possibly extending out to at least 250-500 m from the seismic vessel (observations were not possible farther away). It is not known whether these behavioral effects could affect accessibility of seals to hunters if hunting were occurring near the seismic operation. However, there was apparently no overlap between seal hunting and BPXA's 1996 seismic program, and there was no indication that the seismic program interfered with seal hunting.

4.7 Summary and Conclusions

A total of 422 seals were seen from the source vessel during the 1996 seismic surveys. Of these, there were 304 ringed seals, 24 bearded seals, and 3 spotted seals. The remaining 91 seals were not identified to species.

This analysis of the seal observations indicates that full-array seismic operations influenced seal numbers, distribution, and behavior within a few hundred meters of the source vessel. When a single 120 in^3 airgun was in use, seal numbers, distribution, and behavior were similar to those when seals were exposed to the source vessel without airgun operations. This difference is at least partly understandable on the basis of the large measured differences in the received levels from the array vs. a single airgun (Chapter 3). The distances at which received sound levels from a full array of 11 airguns diminished to 200, 190, 180 and 160 dB re 1 µPa (rms pulse pressure) did not exceed about 44, 257, 1020 and 4900 m, respectively, and were more typically about 31, 240, 970 and 3600 m (Chapter 3). Corresponding distances for a single airgun were much less (Chapter 3).

Overall, vessel-based observers saw seals at nearly identical rates regardless of whether no guns, a single gun, or 8-11 guns (full array) were firing. As would be expected, seals were seen most often close to the boat, and less often at greater distances. However, with full-array seismic, seals were encountered less frequently within 150 m of the source vessel and more frequently at distances between 250 m and the limits of vision, generally near 500 m for most seals. Observed distances of seals from the source vessel tended to be significantly ($P<0.001$) greater with full-array seismic than no seismic. This suggests that some seals tended to avoid the source vessel during operation of the full airgun array.

Behavioral patterns of seals during periods without seismic and during single-gun seismic operations were quite similar, and somewhat different from those with full-array seismic activity. Some differences in behavior in relation to distance were consistent with the hypothesis that seals may tend to remain at the surface at times when the water below the surface is strongly ensonified by seismic pulses. However, some other behavioral data, including the frequencies of dives at various distances during full-array seismic operations, were not consistent with this hypothesis.

Within the safety radius, 160 seals were seen during daylight periods, and another 33 seals were estimated to have been present during darkness. An estimated 17 seals showed avoidance reactions at distances beyond the 250 m safety radius. Thus, the direct estimate of the number of "takes by harassment" is 210. This number does not consider seals that may have been present during daylight surveys but were not seen. This estimate is subject to various assumptions and biases discussed in the text.

Based on the density of seals detected within 50 m of the vessel when seismic operations were not underway (0.30 seals/km^2), it is estimated that about 648 seal "takes" may have occurred during the entire seismic program, and that these "takes" involved about 189 different seals. These figures assume that seals occurring within 250 m of the operating full array (nominal received level 190 dB re 1 µPa, rms pulse pressure) were "taken by harassment". About 404 seals might have been present within the considerably larger area where received levels of seismic sounds exceeded 160 dB re 1 µPa at certain times during the seismic program. Again, these estimates are subject to various assumptions discussed in the text.

Seals did not appear to be displaced far enough from the seismic operation to affect accessibility to hunters, although some local displacement was detected within 250 m of the seismic array. There were some changes in proportional occurrence of various behaviors, possibly extending out to at least 250-500 m from the seismic vessel (observations were not possible farther away). It is not known whether these behavioral effects could affect accessibility of seals to hunters if hunting were occurring near the seismic operation. However, there was apparently no overlap between seal hunting and BPXA's 1996 seismic program, and there was no indication that the seismic program interfered with seal hunting.

4.8 Acknowledgments

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5. WHALES[1]

5.1 Introduction

Two species of cetaceans migrate west through the central Alaskan Beaufort Sea during late summer and autumn: the endangered bowhead whale, *Balaena mysticetus*, and the beluga whale, *Delphinapterus leucas*. There have also been been very occasional sightings of the gray whale, *Eschrichtius robustus*, in the study area. However, gray whales rarely occur east of Point Barrow.

The Bering/Chukchi/Beaufort Sea stock of bowhead whales is currently estimated to contain about 8000 animals, with the lower and upper 95% confidence bounds estimated at 6900 and 9200 animals (Zeh et al. 1995; Small and DeMaster 1995). This bowhead population is believed to be increasing at a rate of about 2.3% per year despite the annual subsistence harvest. The Beaufort Sea stock of beluga whales has recently been estimated to contain 41,610 individuals (Small and DeMaster 1995).

The autumn migration corridors of most bowheads and belugas are farther offshore than the Northstar seismic exploration area. The 1996 Northstar seismic program was conducted within 13 km of the barrier islands. The southern edge of the main migration corridor past the Northstar area is about 20 km offshore for bowheads, and about 70 km offshore for belugas (Frost et al. 1988; Clarke et al. 1993; Moore and Reeves 1993; LGL and Greeneridge 1996). However, in past years, small numbers of both species have been seen closer to shore, including at least four sightings of bowheads well within the planned Northstar seismic exploration area during October 1989 (Treacy 1990; LGL and Greeneridge 1996) and three others near its northern border (Fig. 5.26, 5.27, later). Also, whales in waters well north of Northstar could be exposed to underwater sounds from seismic exploration closer to shore.

The bowhead whale is of special concern because of its endangered status and its behavioral responsiveness to noise pulses from seismic exploration (Richardson and Malme 1993), and because it is the object of a subsistence hunt by Alaskan Eskimos. This includes residents of the village of Nuiqsut. Nuiqsut whalers hunt from camps on Cross Island, located ~20 km east of the eastern edge of the Northstar area (Long 1996). Most bowheads migrate west through the central Alaskan Beaufort Sea during September and early-mid October.

Whales might be disturbed by underwater sounds from the seismic exploration program. Bowhead whales usually show avoidance reactions to seismic vessels operating within several kilometers (Richardson et al. 1986; Ljungblad et al. 1988). Reaction distances may (or may not) be different for whales migrating past a relatively localized seismic operation like Northstar than in the circumstances previously studied. Previous monitoring studies have provided inconclusive results concerning avoidance at longer distances. However, there have been indications that some bowheads may show avoidance at distances as great as 24 km

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(Koski and Johnson 1987). Subtle behavioral reactions are suspected to extend to even longer ranges (Richardson et al. 1986; Richardson and Malme 1993), but the biological significance of those possible reactions is uncertain. Reactions of gray whales to seismic exploration are similar (Malme et al. 1984, 1988). There are no published data on the reactions of belugas to seismic exploration, but they are expected to be able to hear seismic sounds even at long distances (Richardson et al. 1995; Richardson and Würsig in press).

Inupiat whalers are especially concerned that seismic programs may displace some bowhead whales farther offshore, making them less accessible to hunters (Jolles [ed.] 1995; Rexford 1996). Based on their accumulated observations and experience, the Inupiat whalers also believe that whales exposed to seismic and other industrial noises are more "skittish" and difficult to hunt. These concerns were emphasized at a workshop entitled "Arctic Seismic Synthesis and Mitigating Measures Workshop", held in Barrow, AK, on 5-6 March 1997. Inupiat whalers believe that, during autumn migration, bowhead whales migrating west though the Alaskan Beaufort Sea can be displaced northward by as much as 30 miles from their normal migration corridor (Kanayurak et al. 1997).

One of the dominant considerations during the design of this monitoring project was the need to determine, insofar as possible, whether displacement of the bowhead migration corridor occurred during the Northstar seismic program. This study was designed to take into account both the results of previous scientific studies and the accumulated experience of the Inupiat whalers, both of which are useful in formulating hypotheses and study designs.

Whether seismic exploration sounds are strong enough to cause temporary or permanent hearing impairment in any marine mammals that might occur very close to the seismic source is unknown (Richardson et al. 1995:366). In part to avoid any such possibility, the National Marine Fisheries Service (NMFS) has concluded that baleen whales should not be exposed to seismic pulses with received levels above 180 dB re 1 µPa, and that odontocetes should not be exposed to levels above 190 dB re 1 µPa (NMFS 1995). Prior to the field season, these levels were predicted to occur at radii of 650 m and <150 m, respectively.

Specific tasks, objectives and IHA requirements for the monitoring program as a whole are listed in §1.2, "Objectives". The objectives pertaining specifically to whales included

- implementing the shutdown provisions of the Incidental Harassment Authorization if any species of cetacean were detected within 650 m (2130 ft) of the active seismic vessel (amended on 30 August 1996 to 750 m for airgun array operations),
- documenting migration routes and migration timing for bowheads and belugas,
- comparing whale distributions and headings during parts of 1996 with and without airgun array operations,
- comparing whale migrations in 1996 with those in other years, especially those in other years with similar ice conditions but little or no offshore industrial activities,
- determining sound levels to which whales (especially bowheads) seen during seismic operations were exposed (see Chapter 3, PHYSICAL ACOUSTICS MEASUREMENTS), and

- estimating the numbers of whales that may have been disturbed by the seismic program ("taken by harassment") and the numbers that passed within 20 n.mi. [37 km] of the northern edge of the seismic operation when the airguns were in use.

The main methods for monitoring cetaceans were boat-based visual observations whenever airguns were in use and at some other times; aerial surveys conducted daily (weather permitting) from 1 to 21 Sep 1996, including sonobuoy drops; and continuous acoustic monitoring via bottom-mounted acoustic recorders. No cetaceans were seen from the seismic vessel at any time during the 1996 Northstar seismic program. Thus, this chapter is based largely on the aerial surveys and on the ancillary physical acoustics measurement program described in Chapter 3. The acoustics program provided data on exposure of bowheads to underwater sounds from the seismic work. The acoustics program also provided data on calling rates of bowheads near acoustic monitoring locations offshore of Northstar and, for comparison, northeast of Cross Island.

A variety of metric and non-metric measurement units are used in this chapter. Metric units are usually used for distances, but maps also show a nautical mile scale. Non-metric units are used if they were referenced in the associated study objective. Non-metric units are also used when they are the units usually used in describing equipment or procedures.

5.2 Methods

5.2.1 Boat Surveys

Watches for marine mammals were conducted from the seismic source vessel, the *Point Barrow*, throughout the 1996 seismic program, from 24 July to 18 Sep 1996. Chapter 4, SEALS, provides additional details concerning the boat-based observation procedures. In summary, at least one biologist or Inupiat observer watched for marine mammals

- at all times while the airgun(s) were in operation,
- for at least 30 minutes before all planned startups of airguns, and
- at certain other times with no airgun operations.

Fujinon 7 x 50 binoculars were the primary optical equipment. A Bushnell/ITT Night Ranger 250 night vision device was used, but even so, sightability was greatly reduced at night. It is very unlikely that whales >300 m away would have been seen at night if any were present.

Overall, there were 585.5 hours of watching for marine mammals while 1-11 airguns were in operation, and 300.1 hours of watches without airgun operations. Of these, 751.9 hours were in daylight (including dusk and dawn), and 133.7 hours were dark. During September, when bowhead whales migrate through the area, there were 167.1 hours of watches with airgun operations and 69.2 hours without. The September watches included 152.7 hours during daylight (101.3 h with airguns) and 83.6 hours at night (65.8 h with airguns).

No whales of any species were seen during the surveys from the seismic source vessel, either during daytime or at night.

5.2.2 BPXA/LGL Aerial Surveys, 1-21 September 1996

Aerial surveys for marine mammals in and around the Northstar area were conducted daily from 1 to 21 September, weather permitting. A standard survey route was flown daily, weather permitting. Overall, most or all of the planned survey route was surveyed during 9 dates, and parts of the grid were surveyed during five additional dates. Thus, partial or complete survey coverage was obtained on 14 of 21 dates from 1 to 21 September 1996.

Survey Area.—The study area for the BPXA/LGL aerial surveys during September extended from ~30 km west of the western edge of the area where seismic was underway east to 50+ km east of the eastern edge of that area, and from the barrier islands north to 65-85 km offshore (Fig. 5.1). Within this study area two series of systematic north-south transects were flown. The "extensive" transects provided broad-scale survey coverage of the entire study area. The "intensive" transects provided additional opportunities to detect mammals in and near the area of seismic operations:

1. The "extensive" survey grid nominally consisted of 12 transect lines (total length ~840 to ~860 km) spaced 8 km apart. From 1 to 12 September 1996, the extensive lines extended from 149°33'W east to 147°10'W (lines 0-11 on Fig. 5.1). From 13 to 21 September seismic operations were centered farther west, and the aerial survey grid was moved commensurately to the west. The extensive aerial survey lines then extended from 150°25'W to 148°02'W (lines -4 to 7 on Fig. 5.1). During four of the dates from 13 to 21 September, 2-4 of the four "eastern" lines (lines 8 to 11) were flown in addition to some or all western lines (lines -4 to 7). The extensive lines extended from near the barrier islands north to 71°12.5'N in the western part of the study area, and north to 71°00'N in the eastern part. Lines 7 and 8 were not flown south of 70°35'N when fall whaling was occurring at Cross Island (Fig. 5.1).

2. The smaller "intensive" survey grid over and near the area of seismic exploration consisted of 4 shorter transects spaced 8 km apart and midway between the nearby lines of the extensive grid. The intensive lines were midway between extensive transects 2 through 6 during the 1-12 September period (transects 103 to 106 on Fig. 5.1: total length 122 km). The intensive lines were midway between extensive transects -1 through 3 during the 13-21 September period (transects 100 to 103: total length 113 km). These intensive transects extended north from the barrier islands to 70°45'N (transects 102-106) or 70°50'N (transects 100 and 101; Fig. 5.1).

When weather conditions permitted both survey grids to be surveyed, the extensive grid was flown first. Also when weather permitted, transects in each grid were flown in order from west to east, progressing eastward contrary to the normal direction of travel of autumn-migrating bowheads. However, on a few occasions a modified sequence was required because of weather restrictions: occasionally parts of the extensive lines were flown early in the day and the remainder were flown later in the day after fog or low clouds had lifted, or some eastern lines were flown before the western lines because fog or freezing rain prevented surveying the lines in the desired order.

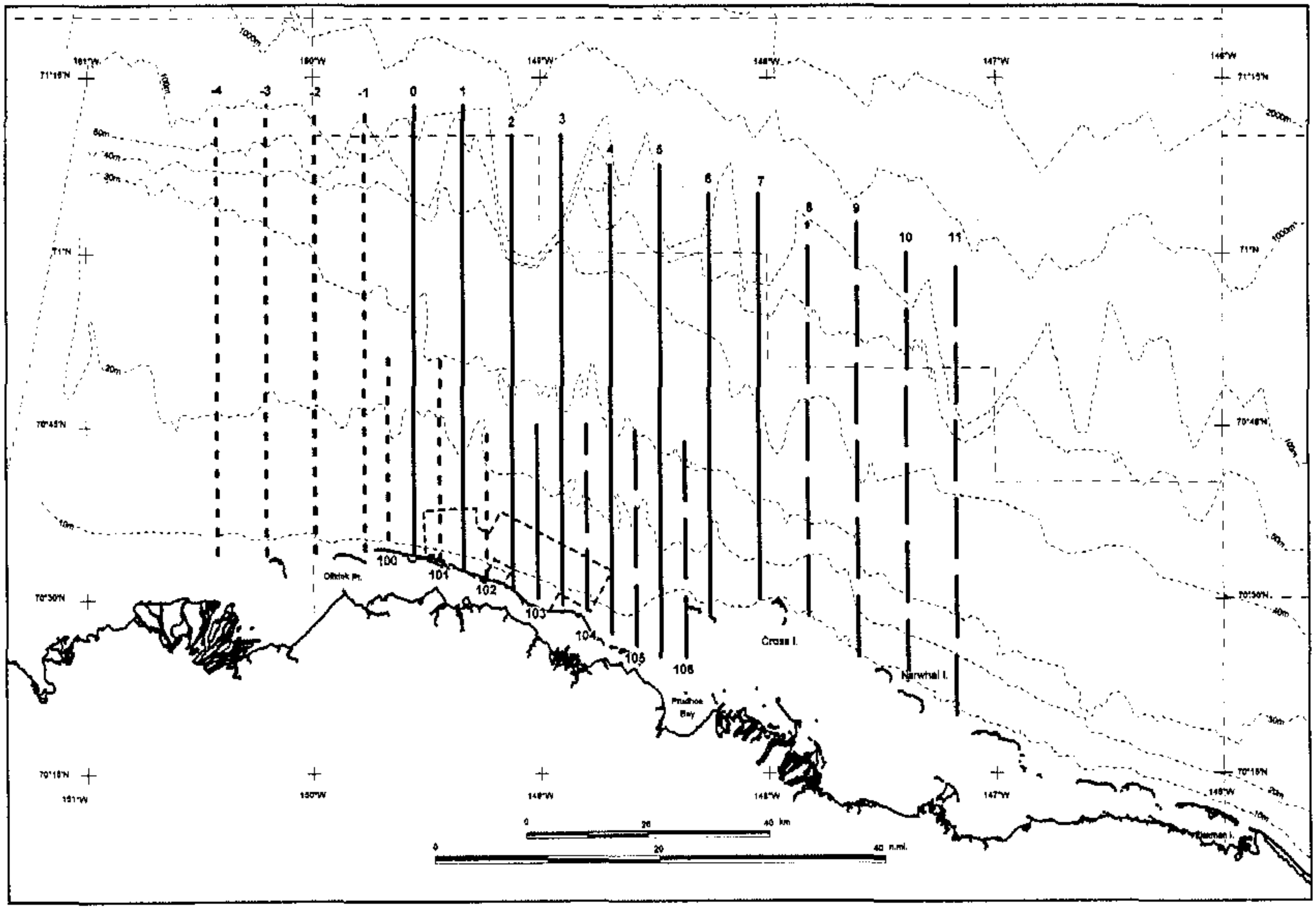

FIGURE 5.1. Standard aerial survey lines flown by LGL during September 1996 in the central Alaskan Beaufort Sea (146°-151°W). Eastern lines depicted by long dashes were part of the standard survey grids flown during the 1-12 September period. Western lines depicted by short dashes were flown starting on 13 September after the seismic operations moved west. Seismic patches shot during September 1996 are outlined.

Survey Procedures.—The surveys were flown in a modified Commander 680FL operated by Commander Northwest of Anchorage, Alaska. This aircraft has been specially adapted for survey work. The special features include upgraded engines, STOL modifications to allow safer flight at low speeds, long range fuel tanks, multiple GPS navigation systems, bubble windows at all observer positions, 110V AC power for survey equipment, and a sonobuoy chute. Two pilots were on duty for takeoffs, landings and ferry flights. During surveys the co-pilot moved to the rear of the aircraft to allow use of his seat by an observer.

Surveys were conducted at altitudes of 900 to 1500 ft (274-457 m) above sea level (ASL) and a groundspeed of 120 knots (222 km/h). The preferred altitude was 1000 ft ASL (305 m), but some surveys were conducted at lower or higher altitudes:

- The Incidental Harassment Authorization issued by the National Marine Fisheries Service (NMFS) authorized us to fly below 1000 ft when necessary to complete surveys. During follow-up discussion, NMFS authorized surveys at altitudes as low as 900 ft if that would allow surveys at times when the cloud ceiling was just below 1000 ft ASL. In 1996, this permitted surveys on several days when weather conditions would have precluded surveys at an altitude of 1000 ft ASL. This greatly increased the effectiveness of the aerial monitoring program.
- There was concern about potential aircraft disturbance to whaling activities based at Cross Island. Accordingly, transects 7 and 8 were not surveyed south of 70°35'N prior to 18 September, by which time whaling had ended for the season. Also, during the whaling season, before starting to survey transects 7-11 each day, we determined whether the whaling crews based at Cross Island were at sea. This was done by radio contact with the Communication Center established under the Conflict Avoidance Agreement between the whalers and BPXA. If the whaling boats were not at sea, transects 7-11 were flown at 1000 ft altitude. If they were at sea, we flew at 1500 ft altitude if the cloud ceiling allowed. If clouds prevented flying at 1500 ft altitude, only the portions of transects 7-11 north of 70°40'N were surveyed, from the highest possible altitude in the 900-1500 ft range. These procedures were designed to provide as much survey coverage of the eastern lines as possible while
    - minimizing potential aircraft disturbance to whales in the whaling area,
    - minimizing the probability of flying over or near whalers, and
    - maximizing the probability that the aircraft would be at high altitude (1500 ft) if it did fly over or near whalers.

The two primary observers occupied the front right (co-pilot's) seat and a seat on the left side of the aircraft, immediately behind the pilot. A third observer, who also operated a computerized data logger, was positioned behind the co-pilot's seat. The third observer surveyed when not occupied with other duties. All observers sat at bubble windows that allowed greater downward visibility than standard windows.

Data Recording Procedures.—The two primary observers recorded the position, time, visibility, sea state, ice cover, and sun glare conditions at the start and end of each transect. All variables except position were also dictated onto audiotape at 2-min (~7.4 km) intervals along every transect. A GeoLink data logger recorded time and aircraft, latitude and longitude at 1-s intervals throughout the flights. The GeoLink system consisted of a portable computer, Trimble GPS unit on a PCMCIA card, and GeoLink data logging software.

For each whale sighting, the observer dictated the species, number, ice conditions, size/age/sex class when determinable, activity, heading, swimming speed category, and sighting cue into a portable audio tape recorder. Also, an inclinometer reading was taken when the animal's location was 90° to the side of the aircraft track. In conjunction with records of aircraft altitude, the inclinometer readings allowed calculation of lateral distances of whales from the transect line. (For pinnipeds and polar bears, only the species, number, and ice conditions were dictated.) In addition to recording all sighting data on audiotape, bowhead whale sightings were also recorded on a data sheet by the third observer, and the sighting location was recorded by the BPXA GeoLink data logger.

Sonobuoys.—A total of 19 individually-calibrated AN/SSQ-57A omnidirectional sonobuoys were dropped within the study area during September 1996 in order to measure ambient noise levels and/or received levels of seismic pulses. These sonobuoys were dropped 16-66 km from the seismic survey operations. We typically dropped at least one sonobuoy ~20 km offshore of the seismic survey area during each day of aerial surveys, whether or not seismic surveys were in progress, and whether or not whales were seen in that area.

On eight occasions when bowhead whales were seen within 20-66 km of the seismic survey area, sonobuoys were dropped near the whale(s) to document sound exposure. During six of these eight occasions either a partial array (2 sightings) or a full array (4 sightings) was operating at the time of the sonobuoy drop. On another occasion a sonobuoy was dropped a few minutes after shooting with the full array had stopped and on the last occasion ambient noise was recorded near the whale. In these cases, the sonobuoy was dropped about 1 km ahead of, or to the side of, the whale. On two occasions when the received level of seismic survey pulses was expected to be high, we used sonobuoys that had been specially modified to attenuate the signals by 20 dB in order to avoid overload. To allow use of sonobuoys in relatively shallow waters, all sonobuoys used in this project had been modified to deploy their hydrophones to a depth of 10 m rather than the normal 18 m shallow setting.

Telemetry signals from the sonobuoys were received aboard the aircraft as it flew back and forth along the aerial survey transects. Four calibrated, wideband FM radio receivers were tuned to the respective sonobuoy radio channels. A TEAC model RD-135T instrumentation-quality digital audio tape (DAT) recorder was used to record the signals with bandwidth 0-10,000 Hz per channel. However, the sonobuoy low frequency limit was effectively 10 Hz. The sonobuoy signals faded in and out depending on distance to the aircraft. Segments selected for analysis were from times when sonobuoy signal reception was good. The signal analyses were done by Greeneridge Sciences Inc. using standard procedures for calibrated analysis of sonobuoy signals and for seismic survey pulses (see §3.2, PHYSICAL ACOUSTICS/Methods).

5.2.3 MMS Aerial Surveys, 1 September-9 October 1996

The Minerals Management Service conducted aerial surveys of marine mammals in the Beaufort Sea from 1 September through 9 October 1996. Their methods were consistent with those used by MMS in previous years (e.g., Treacy 1996), as summarized below. However, to provide additional baseline data relevant to the planned Northstar development, MMS undertook to obtain slightly more survey coverage than normal in MMS survey block 1 (Fig. 5.2). That survey block includes the Northstar area and most of LGL's aerial survey route. During the late summer and autumn of 1996, MMS surveyed transects in MMS block 1 and/ or block 2 and/or the eastern part of block 3 on 13 days within the period 2 September through 7 October MMS transects flown in the Northstar study area during 1996 are mapped in Figure 5.3.

For this report, MMS has provided us with digital files of their 1996 marine mammal sighting and effort data (S.D. Treacy, MMS, pers. comm.). These data included dates, times, locations, number of individuals seen, whale headings, survey routes, and sighting conditions.

5.2.4 Aerial Surveys, 1979-95

The Minerals Management Service and its contractors have conducted aerial surveys of bowhead whales and other marine mammals in the present study area during late summer and autumn each year since 1979. In addition, LGL conducted industry-funded aerial surveys in this area during 1982, 1984, 1985 and (briefly) 1995. Results of those studies are valuable for comparison with results obtained during BPXA/LGL and MMS surveys in 1996. The survey results from each year were documented in a lengthy series of technical reports from the Minerals Management Service, Naval Ocean Systems Center, and LGL Ltd. LGL and Greeneridge (1996) did a retrospective analysis of those data, based on re-analysis of the digital data from the 1979-95 work. Maps similar to those in the retrospective report are included here to facilitate comparisons of aerial survey data from 1996 vs. prior years.

MMS Aerial Surveys, 1979-95.—During the years 1979-95, late summer and autumn aerial surveys sponsored or conducted by MMS were flown over broad portions of the Alaskan Beaufort Sea (Fig. 5.2). The surveys were flown in a Grumman Goose and/or a deHavilland Twin Otter, in recent years flying at an altitude of 1500 ft (457 m). Some earlier surveys were conducted at lower altitudes. The three observers used inclinometers to measure the angle of inclination to each cetacean sighting when the initial sighting location was abeam of the aircraft. The observers and pilots were linked by a common communication system, and conversations and comments could be recorded on audio tape.

The aircraft were equipped with radar altimeters and either a VLF navigation system (OnTrack III or Global Navigation System) or, in recent years, a Global Positioning System. Starting in 1982, an on-board computer that interfaced with the navigation system was used

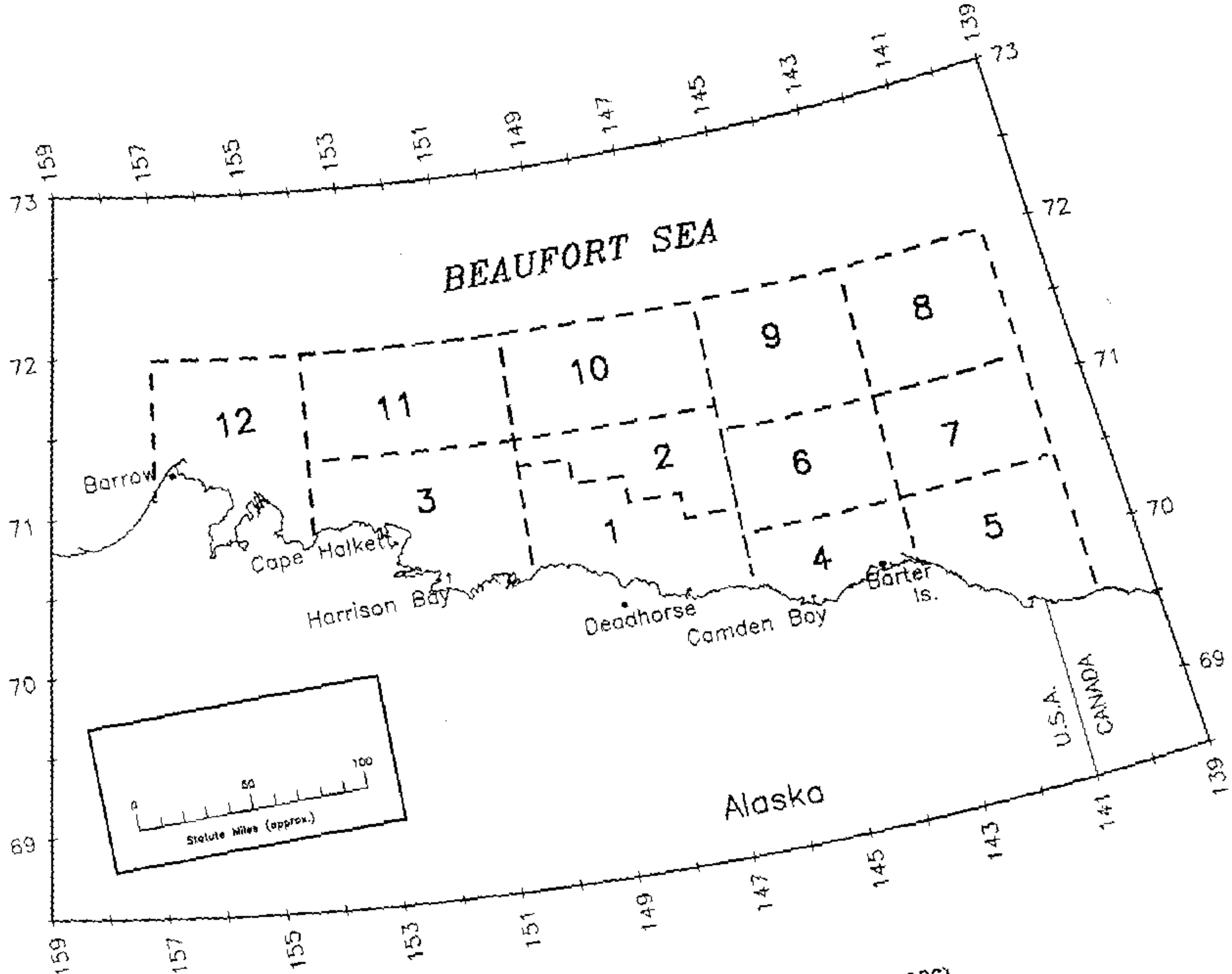

FIGURE 5.2. Alaskan Beaufort Sea, showing MMS survey blocks 1-12 (from Treacy 1996).

FIGURE 5.3. Aerial survey transects flown by MMS during September and early October 1996 in the central Alaskan Beaufort Sea (146°-151°W). Analyses in this report were based on "Transect" sightings within the 147°-150°30'W area (bounded by solid lines). Seismic patches shot during September 1996 are outlined. Excludes "Connect" and "Search" flights.

to automatically store flight data (time and position) for later analysis. In 1983 and following years the on-board computer was also linked to an altimeter (radar altimeter or Global Positioning System) for automatic input of altitudes. Additional data including marine mammal sightings, environmental conditions (e.g., weather, sea state, ice cover), and start and end points of transects and other survey segments were manually entered into the computer. For more details concerning the survey aircraft and other equipment used during the MMS surveys, see the reports summarizing each year's data (e.g., Ljungblad et al. 1987; Treacy 1996).

Daily flight patterns were derived by dividing each MMS survey block into sections of width 30 minutes of longitude wide (approx. 10 n.mi. or 18.6 km at this latitude). One of the minute marks along the northern edge of each 30' section was selected at random to designate one end of a transect. The other endpoint of the transect was determined using a separate randomly generated number along the southern edge of the same section. A straight line, representing one transect, was drawn between the two points. The same procedure was followed for all 30' sections of the survey block. Transects were then connected alternately at their northernmost or southernmost ends to produce one continuous flight grid within each survey block. The selection of the survey blocks to be flown on a given day was non-random, based on such factors as observed weather conditions over the study area and coverage attained during recent days.

Non-transect flight segments were identified as "Connect" segments and "Search" segments. "Connect" segments were the east-west (or similar) flights from the end of one transect to the start of another. "Search" segments were flights to or from the survey block where the transects were flown, or non-random flights to find whales.

MMS transects flown in the central Alaskan Beaufort Sea during the late summers and autumns of 1979-95 are mapped in Figure 5.4 (excluding "Search" and "Connect"). The transect selection procedure used by MMS resulted in N-S "wheatsheaf"-shaped bands of heavy survey coverage alternating with narrower N-S bands of relatively sparse coverage.

In this report we consider only the MMS surveys in the longitude range 146°-151°W, i.e. MMS survey blocks 1, 2 and 10 (146°-150°W) plus portions of MMS survey blocks 3 and 11 (150°-154°W). This area includes waters from 50 km west of the westernmost area of seismic operations in 1996 to 100 km east of the easternmost area of operations. Within this "central Alaskan Beaufort Sea" region, most attention is given to "the Northstar area", from 147°W to 150°30'W, and from the shore north to 71°20'N (about 100 km offshore). All LGL surveys considered in this report were within this latter area.

LGL Aerial Surveys, 1982, 1984, 1985 and 1995.—Also included in the dataset used for retrospective analyses were the results of LGL's industry-funded bowhead surveys conducted in MMS survey blocks 1 and 2 during 1982, 1984, 1985 and 1995 (Hickie and Davis 1983; Davis et al. 1985; Johnson et al. 1986; LGL and Greeneridge 1996). Those studies included repeated aerial survey coverage in and near the Northstar area, including (in 1984-95) some of the same transects that were surveyed in September 1996. The transect grids flown during these studies ranged in length from 480 km (1982) to 910 km (1995). In

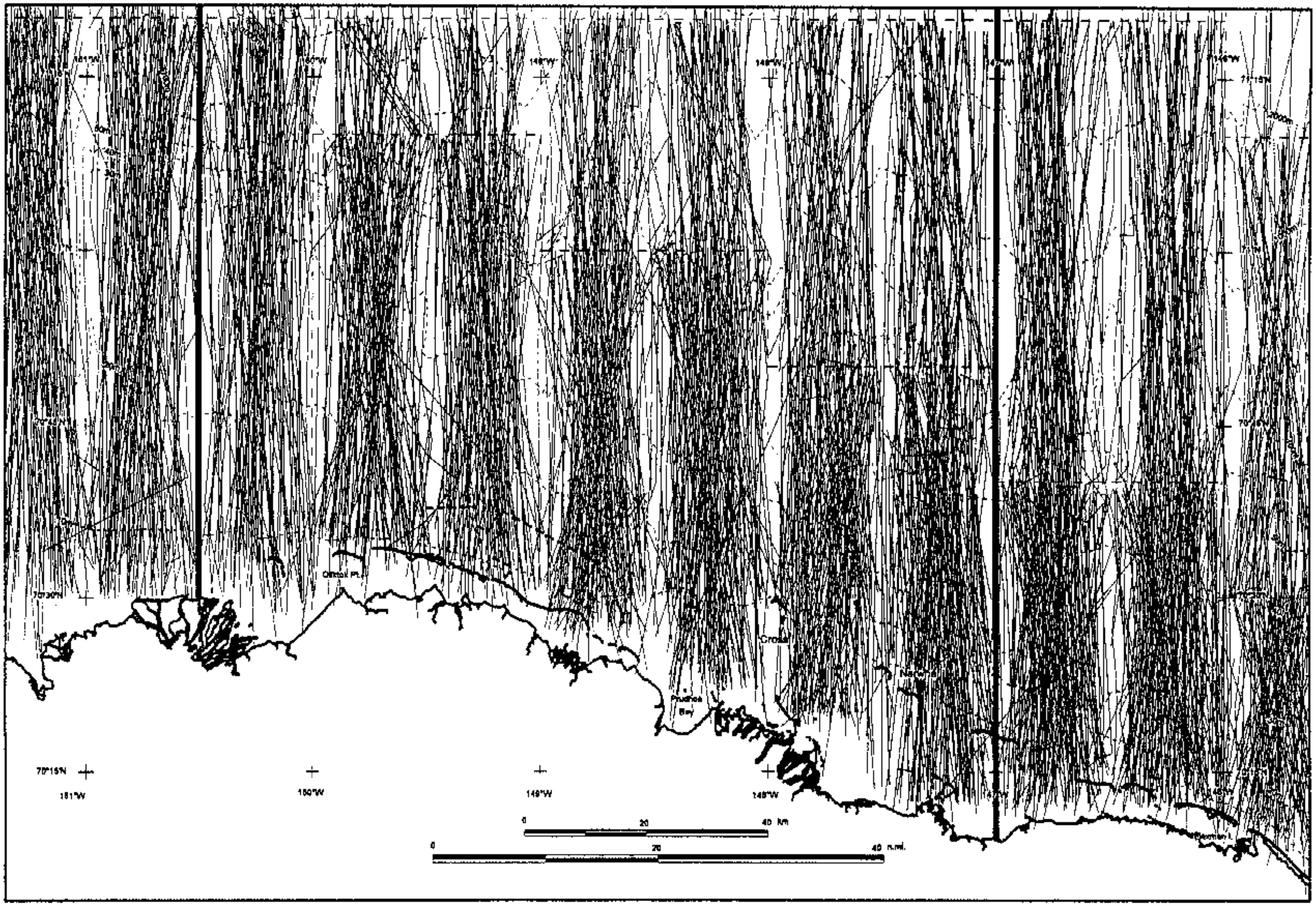

FIGURE 5.4. Aerial survey transects flown by MMS and NOSC during late summer and autumn of 1979-95 in the central Alaskan Beaufort Sea (146°-151°W). Analyses in this report were based on "Transect" sightings within the 147°-150°30'W area (bounded by solid lines). Seismic patches shot during September 1996 are outlined. Excludes "Connect" and "Search" flights.

general, the same survey grid was flown each day when weather permitted. The survey grids flown in these studies are mapped in Figure 5.5.

TABLE 5.1. Dates of LGL's previous surveys in the Northstar region, and total lengths of daily survey patterns.

Year	Survey Dates First	Survey Dates Last	# Days with Surveys	km of Surveys/ Day*
1982	30 Sep	13 Oct	13	480
1984	16 Sep	14 Oct	16	644
1985	13 Sep	20 Oct	26	655
1995	23 Aug	29 Aug	3	910

* On days when grid(s) were completed.

The survey methods used during the 1980s were similar to those during the 1996 monitoring work, but differed in some respects. In the 1980s the surveys were generally conducted from a deHavilland Twin Otter (Series 200 or 300) equipped with a radar altimeter. The on-board VLF/Omega navigation systems were the GNS 500A (1982 and 1985) and the Collins LRN-70 (1984). The surveys were flown at an altitude of 500 ft (152 m). Standard survey speeds ranged from 200 to 222 km per hour during the three years. For 1984 and 1985, inclinometer data are available to determine the distances of marine mammal sightings from the centerline of the transect. In 1982 marine mammal sightings were categorized as "on-" or "off-" transect based on sighting angles determined with an inclinometer. On-transect sightings were those sightings seen within the 700 m strips from 100 to 800 m on either side of the aircraft. For 1982 data, the on- or off-transect designations are known but the inclinometer angles are not available for retrospective analyses. The survey methods in 1995 were similar to those used by LGL in 1996, as described above.

The LGL surveys during 1982, 1984-85 and 1995 contributed a significant proportion of the total survey coverage conducted during the 1979-95 period within the region around Northstar. Figure 5.6 summarizes the available survey coverage. The LGL surveys involved near-daily coverage of the area near Northstar, whereas the MMS surveys sampled a much wider area with less frequent coverage near Northstar. Also, the LGL transects within this area were spaced closer together than is normal during the wide-ranging MMS surveys.

5.2.5 Analyses of Aerial Survey Data

Seismic Status in 1996.—Seismic activities when each aerial survey was flown were determined from the data file compiled by the marine mammal observers on the seismic source vessel (see §2.3). Aerial surveys or portions thereof were categorized as "no seismic" (0 guns firing), "single gun" seismic (1 gun firing), "partial array" seismic (2-7 guns firing), "full array" seismic (8-11 guns firing), and "post-seismic". We assumed that "full array" seismic operations might have a residual effect on whale distribution for some time after the

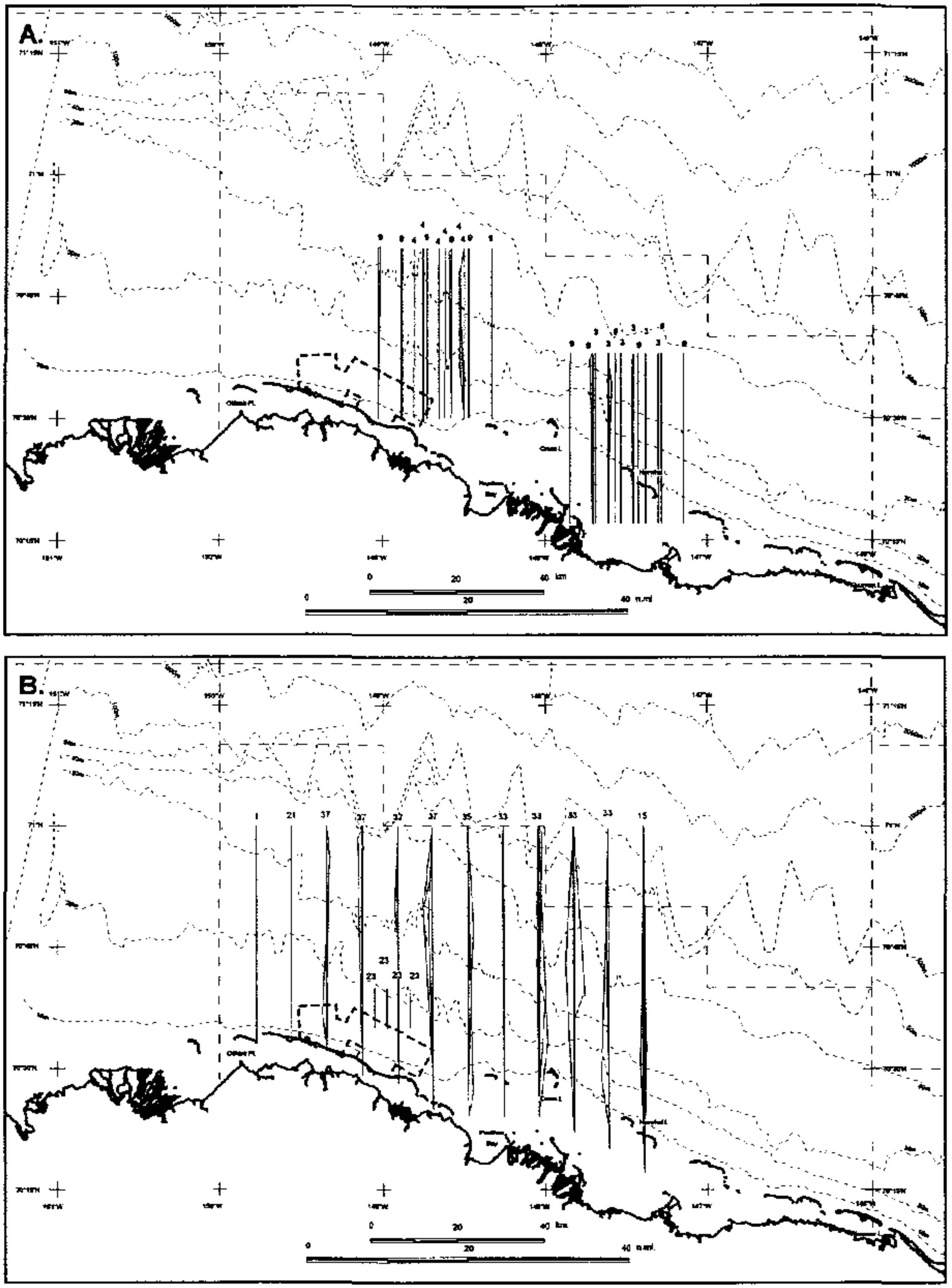

FIGURE 5.5. Aerial survey transects flown by LGL during *(A)* 1982, *(B)* 1984-85, *(C)* 1995 and *(D)* 1996 in the central Alaskan Beaufort Sea (146°-151°W). Number at the N end of each transect indicates the number of times that transect was surveyed. Analyses were based on "Transect" sightings within the 147°-150°30'W area. Seismic patches shot during September 1996 are outlined. Excludes "Connect" and "Search" flights.

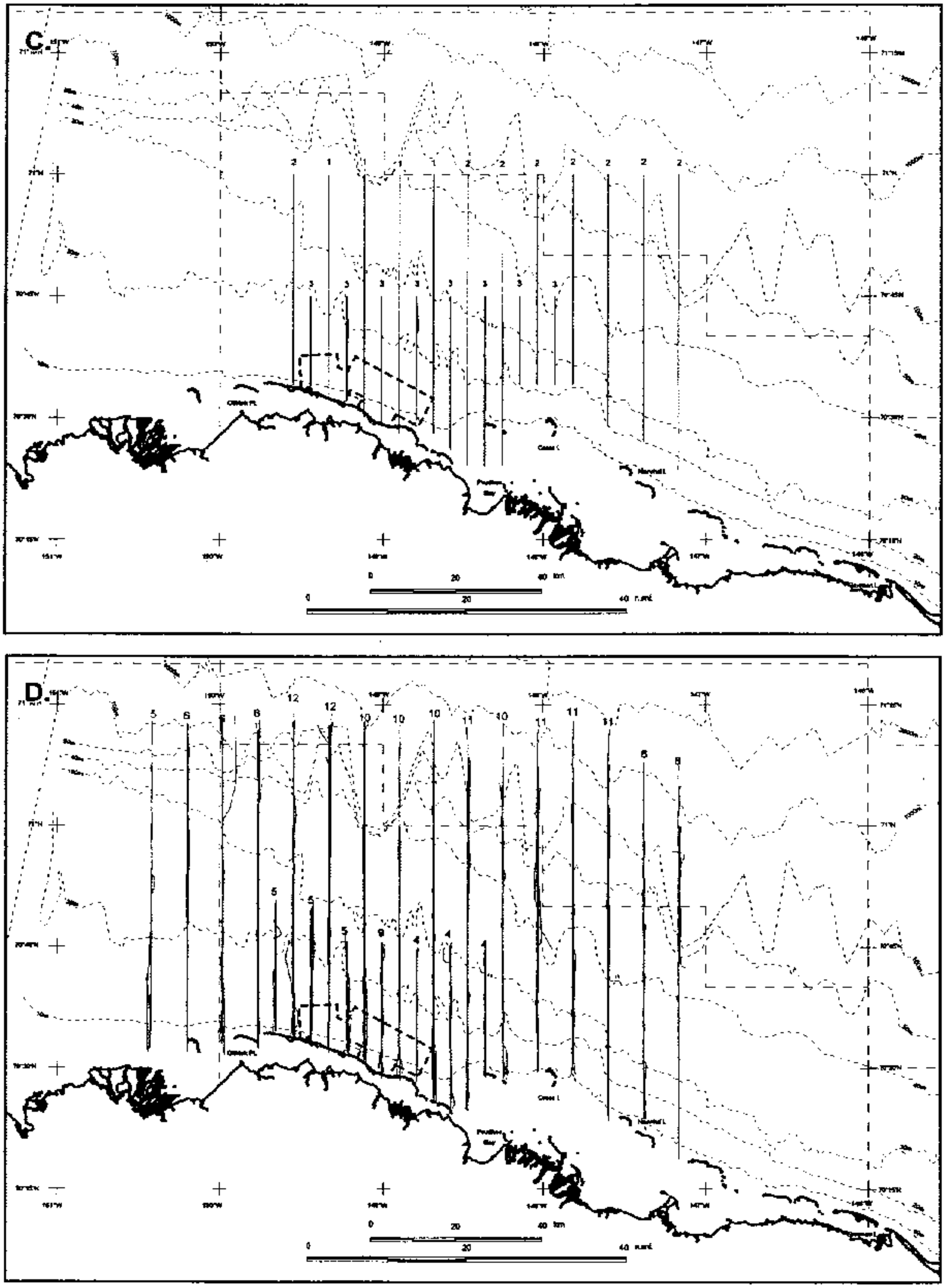

FIGURE 5.5. Concluded.

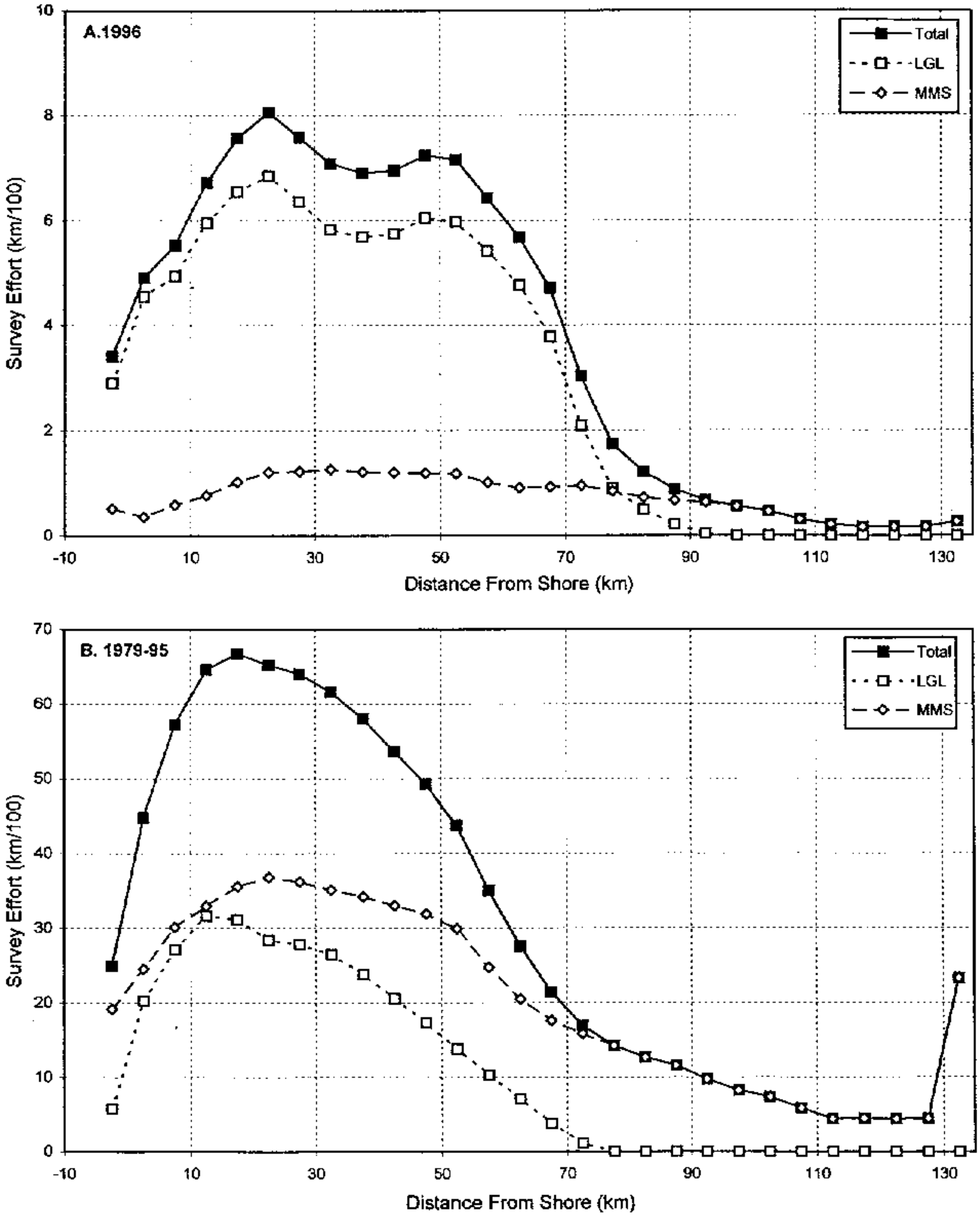

FIGURE 5.6. Kilometers of aerial survey effort at various distances from shore within the Northstar region (147°-150°30'W) during late summer and autumn, including only "Transect" surveys. *(A)* 1996. *(B)* 1979-95. Surveys with poor sightability are excluded.

end of seismic operations. Therefore, survey effort and whale sightings during "no seismic" periods up to 3.5 hours after a period of "full array" seismic operations were categorized as "post-seismic".

The "full array" periods were often interrupted by brief periods of no and/or "partial array" seismic. "Partial array" periods were often interrupted by brief periods of no seismic. These interruptions were typically 3-10 minutes in length and included time between seismic lines, shutdowns for seals sighted within the safety zone, and equipment malfunctions. Some longer interruptions, to a maximum duration of one hour, were also considered part of a "partial array" or "full array" period. Only two bowheads were sighted during "partial array" seismic periods. Both were sighted during periods when an array of 5 guns was firing. The source level of the five-gun array is only about 4-7 dB lower than that of the "full" (8-11 gun) array. Also, these two sightings occurred <3.5 h after a lengthy period of "full array" seismic and were therefore in the "post-seismic" as well as "partial array" seismic categories. Given these facts, along with the small sample sizes for each seismic category, the following analyses often combine "full array", "partial array", and "post-seismic" periods into an "all seismic" category for comparison with periods when there was no seismic either at the time or within the preceding 3.5 h.

Mapping.—This report includes maps showing the sighting locations of cetaceans during 1996 and various combinations of other years during 1979-95, including LGL and MMS data. The maps show sightings in the 146°-151°W region, from the shore north to about 71°20'N. (Maps for beluga whales extend farther north.)

Each sighting symbol on these maps represents a sighting of one or more individual whales. LGL and MMS sightings during the 1-20 September 1996 period are shown by triangular and circular symbols, respectively. Whales sighted by MMS after 20 September were not exposed to either seismic pulses or associated vessel noise. These sightings are indicated by squares. Sightings along formal transects (regardless of distance from trackline) are shown as filled symbols. Sightings during "Connect" or "Search" legs are shown as open symbols, and are not considered during most analyses.

Some whales were sighted along transects at times when sighting conditions were poor, i.e. Beaufort Scale 5 or more, or lateral visibility less than 1 km due to fog, glare, rain or snow. These sightings, and the associated survey effort under poor conditions, have been excluded from some of our analyses of sightings per unit effort. Also, a few surveys coded as "Transect" in the MMS datasets were actually "Connect" or "Search" flights. These were re-coded accordingly before use in the present maps and analyses. For both reasons, the total number of sightings during "Transect" surveys, and the total amount of "Transect" survey coverage, is slightly lower with our procedures than would be obtained by direct analysis of the MMS database.

The maps (and analyses) exclude sightings coded as "duplicates" or "repeats" of previous sightings, i.e. same animal(s) seen by more than one observer or on more than one occasion. On the 1996 maps, sightings during seismic periods are plotted as large symbols and are further distinguished as full array ("F"), partial array ("P"), or post-seismic ("PS") sightings. There were no bowhead sightings during single-airgun periods.

The headings of whales, i.e. the directions in which they were oriented, are shown on the maps when headings were recorded. Headings in the MMS database were coded relative to Magnetic North; these were converted to headings relative to True North before mapping. Heading arrows are shown on sighting maps regardless of the activity of the whale. However, in most analyses of headings, we distinguished whales recorded as "swimming" from whales engaged in other activities such as milling, feeding, socializing, or resting.

The six "patches" where seismic activity occurred during September 1996 are outlined on most maps of the study area (e.g., Fig. 5.1). On daily survey maps, the "patch" (if any) where the source boat was shooting seismic during the aerial survey, or ≤3.5 h prior to it, is shaded. The MMS survey blocks (as shown on Fig. 5.2) are also outlined on our maps. The bathymetric contours shown on the maps were developed during this project in 1995, based on all available depth soundings. Sounding data, obtained on CD-ROMs from NOAA, included *Hydrographic Survey Data, Vol. 1, vers. 3.1,* and *Marine Geophysical Data/Bathymetry, Magnetics, Gravity, vers. 3.2.* Contours were developed using ArcInfo. In some parts of the study area, the locations of the new depth contours differ appreciably from those that various authors have used on their maps.

Distances from Shore.—The maps described above provide much of the distributional information. However, they are difficult to interpret because survey effort varied greatly with distance from shore. Also, relative amounts of survey effort at different distances from shore have varied considerably from year to year. LGL and Greeneridge (1996) re-analyzed bowhead and beluga distributions during 1979-95 vs. distance offshore, taking account of the survey effort at each distance from shore. Similar analyses of the 1996 data and comparisons with some earlier years are included in this report.

We divided the analysis region (147°-150°30'W for this report) into a series of strips, each 5 km in width, oriented parallel to the approximate orientation of the coast (113°-293° True; Fig. 5.7). The "0 km from shore" reference point is near the southern edge of the Northstar seismic survey area, along or near the barrier islands. Airgun operations during September 1996 extended from 2 km inshore to 13 km offshore, with almost all operations being within 11 km of the "0 km" line (Fig. 5.7). Waters inshore of the "0 km" line are shallow nearshore waters, in some cases inside lagoons. Given the irregularities in the coastline, and the presence of islands along some but not all parts of the coast, we believe that it is more useful to categorize distance offshore relative to a straight line approximating the orientation of the coast, the depth contours, and the main whale migration corridor than to measure the distance from each whale sighting to the closest land.

We used MapInfo, supplemented by specially-written MapBASIC computer code, to determine the number of whale sightings and individuals, and the number of kilometers of transect survey coverage, within each 5-km distance-from-"shore" strip during 1996, 1994-95, and various other combinations of years. These analyses excluded non-systematic "Connect"

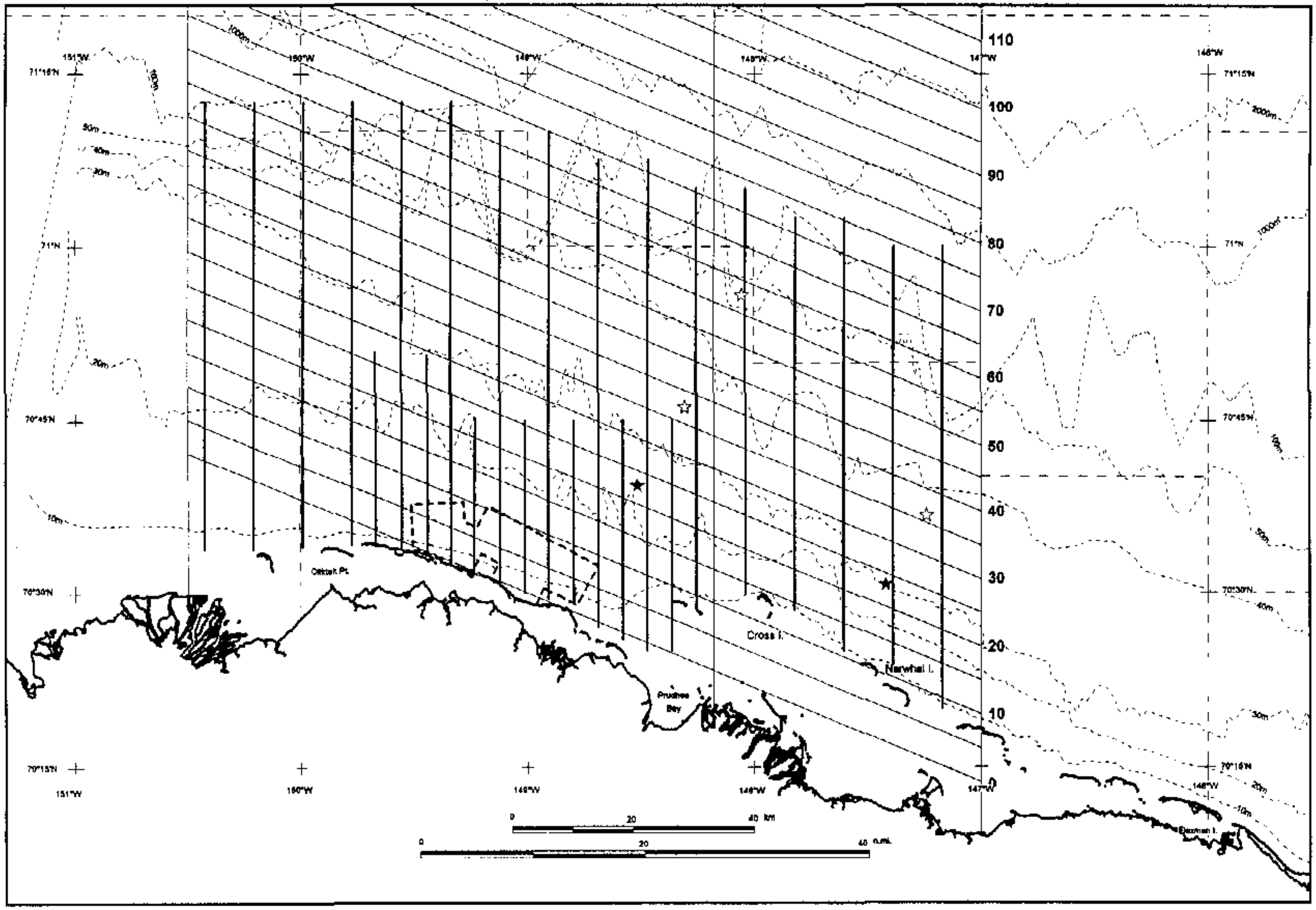

FIGURE 5.7. Categorization of the Northstar region (147°-150°30') by 5-km distance-from-shore intervals. The intervals, which continued out to 130 km offshore, were used to tabulate mammal sightings and survey effort by distance from shore. The most inshore line is defined as the "0 km offshore" line; sightings and survey effort south of that line were also tabulated. Stars show locations of bottom-mounted acoustic recorders; solid stars denote recorders retrieved in mid Sep. 1996 whose data were subsequently analyzed.

and "Search" survey effort and sightings. Survey effort and sightings under poor conditions (Beaufort state ≥5 and/or visibility <1 km) were included in some analyses and excluded from others, as specified in the text and associated Figure captions. Sightings or individuals per unit effort were determined for each distance from shore strip by dividing the number of sightings (or individuals) seen in a strip by the number of kilometers of transect coverage in that strip. In some cases the sightings and/or effort in 5-km strips were limited, so for many graphs adjacent 5-km strips were combined to form 10-km strips.

All analyses described in this report are based on the region from 147°W to 150°30'W. The 1979-95 retrospective analyses (LGL and Greeneridge 1996) had been based on longitudes 147°-150°W. The westward extension from 150° to 150°30' allows for the westward extension of the seismic program and monitoring surveys during the 13-20 September 1996 period, when seismic work was done in the two most westerly "patches".

The numbers of bowhead sightings at different distances from shore are compared for periods with and without seismic exploration using Kolmogorov-Smirnov tests (Siegel 1956; Conover 1971), hereafter called K-S tests.[2] However, this simple comparison does not correct for variable effort at different distances offshore. To do that, we also applied the K-S test to the sightings-per-unit-effort data. The number of sightings was used as the sample size for comparisons of sightings per unit effort. Data from 5-km strips far offshore, where there was little survey coverage, were combined with adjacent survey strips to minimize problems involving anomalously high sightings-per-unit-effort figures when 1 or 2 sightings occurred in regions with little survey effort. Sightings-per-100-km data for each distance-from-shore category were converted to a cumulative distribution, which was then converted to a "0 to 1" cumulative distribution in the usual manner for K-S tests.

This approach has a major advantage over analysis methods previously applied to whale sighting data in the Alaskan Beaufort Sea: it corrects for the widely varying survey effort at different distances from shore. However, there are some concerns about the approach (J. Zeh, Univ. Washington, pers. comm.).

- One concern is that the statistical power of a K-S test diminishes when the data are grouped (here by 5 km distance-from-shore categories), with a further decrease in power as the categories are broadened. With grouped or "tied" data, the test is valid but conservative (Conover 1971; Hollander and Wolfe 1973). Grouping of distances from shore was necessary in order to relate sightings to survey effort. The loss of power can be minimized by using a larger number of narrow categories. For this reason, we used 5-km categories whenever possible when doing K-S tests, even though 10-km categories would result in a smoother distribution of sightings-per-unit-effort vs. distance from shore.

[2] The K-S test cannot be applied to the numbers of individuals at various distances from shore because individuals in a single group are not statistically independent.

- Another concern is that is that bowhead sightings are presumably not all strictly independent of one another. This is especially true if, as is likely, the movements of some widely-spaced bowheads are coordinated via acoustical communication. Thus, the real number of statistically independent observations may be unknown (and unknowable), but less than the recorded number of sightings.
- The distribution and numbers of bowheads and of bowhead sightings in the surveyed area may be affected simultaneously by many factors. The K-S procedure does not allow simultaneous consideration of all these factors. A multivariate approach would be desirable.

More complex multi-variable approaches have been suggested for analysis of factors (anthropogenic and natural) affecting survey data concerning animal distribution (e.g., Augustin et al. 1996; J. Zeh, pers. comm.). However, given the small number of bowhead whale sightings during periods with seismic exploration in 1996 (see §5.3), we have not yet attempted to apply these approaches. If similar data from one or more additional years with seismic exploration become available, these approaches should be pursued.

Seasonal Occurrence.—Sightings during survey flights in the 147°-150°30'W region were compiled by 5-day periods. These analyses were restricted to "Transect" sightings in order to allow meaningful calculations of sightings and individuals per unit effort during different parts of the season. Thus, "zero" sightings or individuals in a particular date range means no sightings during "Transect" flights, not necessarily that there were no sightings on those dates. Results from 31 August were included with those from 26-30 August.

Year-to-Year Comparisons.—Each autumn from 1979 to 1995 has been categorized as a light, moderate or heavy ice year in the various reports describing the MMS aerial surveys. In recent years these assessments have been based on reports from the Naval Ice Center (e.g., Naval Ice Center 1997). The years have been categorized as follows:

- Light ice years, 1979, 1981, 1982, 1986, 1987, 1989, 1990, 1993, 1994, 1995;
- Moderate ice years, 1984, 1985 and 1992;
- Heavy ice years, 1980, 1983, 1988 and 1991.

The MMS aerial survey reports summarize bowhead distribution in the three groups of years based on water depths at the sighting locations of bowheads seen along transects.

The 1996 season was classified as a light ice year (S.D. Treacy, MMS, pers. comm.), notwithstanding the substantial amount of ice encountered during seismic work in and near Northstar during the late summer of 1996.

The 1979-95 period for which aerial survey data are available included years with varying amounts of offshore industrial activity as well as varying ice cover. Both industrial activity and ice conditions may influence bowhead whale distribution, migration timing, or both (LGL and Greeneridge 1996). Hence, the inter-year comparisons in the present report are restricted to years with ice conditions similar to those in 1996, and to years when there was either considerable or little offshore industrial activity in the central Alaskan Beaufort Sea.

Bowhead sightings in the Northstar region during 1996, a "light" ice year with seismic exploration, were compared with the bowhead sightings in the same region during previous light ice years when there was little or no offshore industrial activity. Of the various light ice years during which whale surveys were conducted,

- during 1994 and 1995, there was little or no industrial activity in the Northstar area or in waters east to Camden Bay;
- during 1982, 1987, 1989, 1990 and 1996, there was light ice but also considerable marine seismic exploration and/or artificial island activity in or near the Northstar region, often combined with drilling operations off Camden Bay.

The years 1979, 1981, 1986 and 1993, also with light ice, have been excluded because of uncertainties about the amount of industrial activity near Northstar during those years.

Thus, 1994-95 were considered to be "control" years, with light ice and little or no offshore industrial activity. There were only 43 "Transect" sightings of bowheads in the Northstar region during the 1994-95 period, excluding periods with poor sighting conditions. The great majority (42) of those sightings were from 1995. Thus, the "control" sample consists almost entirely of data from one year, 1995.

The ice conditions in 1996 ranked 11th mildest of the 44 years ranked by the Naval Ice Center in the 1953-96 period (Naval Ice Center 1997). However, considerable pack ice was present in the Northstar region during the latter part of the summer. In an attempt to increase the size of the "control" sample, we considered combining 1994-95 data with any "moderate" ice years with little industrial activity. This seemed to be a reasonable approach because no significant differences had been found between bowhead distributions in light and moderate ice years (LGL and Greeneridge 1996). However, all of the moderate ice years (1984, 1985, and 1992) during the period with aerial survey data (1979-95) were years with substantial offshore industrial activity in or near the Northstar region. Thus, the "control" years consist only of 1994-95.

Besides comparing bowhead distribution, headings and migration timing in 1996 (seismic program) vs. 1994-95 (control years), we also compared the bowhead data from all light ice years having substantial industrial activity (1982, 1987, 1989, 1990 and 1996) vs. 1994-95.

5.2.6 Determination of Estimated Take by Harassment

Recent NMFS practice in situations involving intermittent impulsive sounds like seismic has been to assume that a "take by harassment" (Level B) may occur if baleen whales are exposed to received levels of sounds exceeding 160 dB re 1 µPa (NMFS 1995). The reaction threshold for toothed whales, including belugas, is unknown but presumably higher because of their poorer hearing sensitivity at low frequencies (NMFS 1995; Richardson et al. 1995; Richardson and Würsig in press). However, the IHA required information about the number of belugas (as well as bowhead and gray whales) that may have been harassed as a result of exposure to seismic pulses at received levels ≥160 dB re 1 µPa.

Received levels of seismic pulses from the array of 11 airguns used in 1996 diminished below 160 dB re 1 µPa at an average range of ~3.6 km and a maximum range of 4.9 km from the airgun array (see Chapter 3). The actual ranges were subject to variation with time and location depending on water depth, number of airguns in use, aspect, and no doubt other factors as well (Chapter 3).

The aerial survey[3] and sonobuoy results from 1996 were examined to determine whether there was evidence that any of the whales seen were exposed to seismic sounds with received levels ≥160 dB re 1 µPa. However, because only very small percentages of the total populations of migrating bowhead and beluga whales are seen during aerial surveys, this is not an adequate method for estimating "take by harassment".

An alternative and more realistic approach is to estimate, for each whale species, the number of whales that might have been exposed to seismic pulses with received levels ≥160 dB re 1 µPa based on

- the total numbers of whales that migrate west through the Alaskan Beaufort Sea during late summer and autumn,
- the proportion of the whale population passing the Northstar longitude up to 18 September, the date when the 1996 seismic program ended,
- the numbers of hours with and without seismic survey operations during the whale migration period,
- the estimated distance from the seismic boat within which received levels of seismic pulses were ≥160 dB re 1 µPa during "full array" operations (average of 3.6 km, maximum of 4.9 km in 1996—see Chapter 3),
- the proportions of the seismic survey operations at various distances from shore, and
- the proportion of the whale population migrating close enough to shore to be in areas where received levels of seismic pulses would be ≥160 dB re 1 µPa.

This approach is applied on pages 5-87 and 5-102 to estimate the numbers of bowheads and belugas that might have been exposed to received levels of seismic sounds ≥160 dB re 1 µPa.

As noted in §5.1, the maximum distance at which sounds from a seismic boat may affect bowhead movements or behavior is uncertain, but may exceed the 160 dB radius. Inupiat whalers believe that avoidance effects may extend as far as 30 miles. The peer review group asked that we estimate the number of bowheads passing within 20 n.mi. [37 km] of the northern edge of the seismic exploration area during times when airgun operations were underway. To do this, the approach described in the preceding paragraph was repeated for the 20 n.mi. distance criterion.

[3] No whales were seen by the marine mammal monitors on the seismic source vessel during the 1996 Northstar seismic program, so their observations are not directly relevant here.

5.3 Bowhead Whale

5.3.1 Aerial Survey Effort and Sightings, 1996

Aerial survey effort and numbers of bowhead sightings during the 1996 Northstar marine mammal monitoring program conducted by LGL for BPXA are summarized in Table 5.2. The survey effort data in Table 5.2 are raw figures uncorrected for periods of reduced sightability. Some of the following analyses (e.g., headings) use the raw uncorrected data. Other analyses (e.g., distance from shore) use both raw data and data corrected for periods of poor sightability. Details concerning individual bowhead sightings during the 1996 Northstar program are summarized in Table 5.3.

Aerial survey coverage of one or both of the Northstar survey grids was obtained on 14 days during the 1-21 September study period (Table 5.2). All or most of the survey transects were completed on 9 days. Substantially reduced coverage of the survey grids was obtained on 5 additional days when parts of the study area could not be surveyed because of low clouds, precipitation, high sea states, or some combination of those problems. On the other seven dates, effective surveys were prevented by those types of poor weather.

Daily Survey Results.—This section, and the accompanying Figures 5.8 through 5.21, summarize the Northstar survey results on a day-by-day basis. Readers who do not require this level of detail can skip to "Summary of Northstar Surveys" on p. 5-40.

The first partial (166 km) survey was flown on 3 September. Low cloud cover restricted survey coverage to the northeastern portion of the extensive grid. Full array seismic was operating at the time the survey was flown. No bowheads were sighted (Table 5.2, Fig. 5.8).

Nearly complete (935 km) coverage of the extensive and intensive grids was obtained on 5 September (Fig. 5.9). No seismic was being shot at the time of the survey. Fourteen whales were sighted. Many of the whales were fairly close to the Northstar area, and all of the sightings were in waters with high sea states (Fig. 5.9, Table 5.3).

Limited survey coverage was obtained on 6 September (348 km) and 7 September (260 km; Table 5.2). On both days poor weather and visibility in the southern portions of the study area restricted survey coverage to the northern areas (Figs. 5.10, 5.11). No bowheads were sighted on 6 September. There was one incidental sighting of two bowheads on 7 September, fairly near the Northstar area (Fig. 5.11). The seismic array was not operating on either date.

On 8 September, 850 km of aerial surveys were flown, including both the extensive and intensive grids. This survey coverage resulted in the sighting of three bowheads, located well offshore (Fig. 5.12). The transects were flown during a "no seismic" period.

On 9 September, all extensive and intensive transects were surveyed (total 972 km; Table 5.2). This survey coverage was divided between periods with no seismic (658.5 km) and

TABLE 5.2. Summary of LGL aerial survey effort and bowhead sightings in the Northstar region by date and seismic periods, 1-21 September 1996.

	Survey			No Seismic			Single Gun Seismic			Partial Array 2-7 guns			Full Array 8-11 guns			Post Seismic			Total Seismic			Total Seismic and Non-seismic		
	Start	End	Dur.	Km	Sightings	Individuals	Km	Sightings	Individuals	Km	Sightings	Individuals	Km	Sightings	Individuals	Km	Sightings	Individuals	Km	Sightings	Individuals	Km	Sightings	Individuals
1 Sept	-	-																	0			0	0	0
2 Sept	-	-																	0			0	0	0
3 Sept	16:41	17:37	00:56										166	0	0				166	0	0	166	0	0
4 Sept	-	-																	0			0	0	0
5 Sept	09:30	14:54	05:24	935	12	14													0	0	0	935	12	14
6 Sept	16:35	18:45	02:10	348	0	0													0	0	0	348	0	0
7 Sept	09:48	11:15	01:27	260	1	2													0	0	0	260	1	2
8 Sept	10:46	14:36	03:50	850	2	3													0	0	0	850	2	3
9 Sept*	10:02	13:16	03:14	658	5	6	0	0	0				313	1	1				313	1	1	972	6	7
" "	14:56	17:00	02:04																"			"	0	0
10 Sept	09:52	13:36	03:44										972	3	3				972	3	3	972	3	3
" "	15:15	17:33	02:18																"			"	0	0
11 Sept	-	-																	0			0	0	0
12 Sept	-	-																	0			0	0	0
13 Sept	10:57	13:12	02:15	426	2	2													0	0	0	426	2	2
14 Sept	19:13	19:57	00:44										145	0	0				145	0	0	145	0	0
15 Sept**	10:12	14:23	04:11							791**	2	2	315	0	0				1107	2	2	1107	2	2
" "	16:36	18:34	01:58																				0	0
16 Sept	10:59	16:05	05:06	854	0	0													0	0	0	854	0	0
17 Sept	-	-											0	1	1				0	1	1	0	1	1
18 Sept	13:53	19:11	05:18										349	2	2	525	8	12	875	10	14	875	10	14
19 Sept	10:53	15:01	04:08	1128	9	17													0	0	0	1128	9	17
" "	16:29	18:32	02:03																				0	0
20 Sept	11:14	15:42	04:28	1189	10	12													0	0	0	1189	10	12
"	17:28	19:43	02:15																				0	0
21 Sept	-	-																	0			0	0	0
																							0	0
Total				6648	41	56	0	0	0	791	2	2	2259	7	7	525	8	12	3576	17	21	10225	58	77
No./100 km					0.62	0.84		-	-		0.25	0.25		0.31	0.31		1.52	2.28		0.48	0.59		0.57	0.75

* 0-gun km on 9 Sept. includes 3 brief (<3 min) periods of seismic "testing" beginning at 12:56:43, 15:11:38, and 15:19:27.

** On 15 September, 436 km of the aerial transects flown during "partial array" seismic were concurrent with 436 km of "post-seismic" aerial surveys (not shown in "Post Seismic" column).

TABLE 5.3. Summary of LGL bowhead sightings during Northstar aerial surveys, 1-21 September 1996.

Date	Time	No. Bhds.	Trans. No.	Lat.	Long.	No. Calves	Behav.	Orient. (Deg. T)	Swim Speed	Beaufort Scale	Sighting Type	Exclus. From Anal.*	Km from Shore Band	Seismic State	Km From Source	Bearing (Deg. T) From Source
5 Sep	105305	1	105	70 34.2	148 34.5	0	Rest	180	None	5	Transect	Optional*	10-15	None	-	-
"	105308	1	105	70 34.2	148 34.5	0	Rest	90	None	5	Transect	Optional*	10-15	"	-	-
"	110750	1	106	70 33.8	148 21.5	0	Swim	150	Slow	5	Transect	Optional*	15-20	"	-	-
"	121100	1	4	70 32.3	148 41.0	0	Swim	80	Medium	6	Transect	Optional*	5-10	"	-	-
"	121149	3	4	70 37.5	148 41.0	0	Rest	-	None	5	Transect	Optional*	15-20	"	-	-
"	125020	1	5	70 31.6	148 28.0	0	Swim	300	Medium	6	Transect	Optional*	10-15	"	-	-
"	125017	1	5	70 31.6	148 28.0	0	Swim	90	Medium	6	Transect	Optional*	10-15	"	-	-
"	125731	1	6	70 33.0	148 15.0	0	Rest	20	None	5	Transect	Optional*	15-20	"	-	-
"	125731	1	6	70 33.0	148 15.0	0	Rest	360	None	5	Transect	Optional*	15-20	"	-	-
"	132743	1	7	70 39.0	148 02.0	0	Rest	180	None	5	Transect	Optional*	25-30	"	-	-
"	141424	1	10	70 25.8	147 22.0	0	Swim	270	Medium	6	Transect	Optional*	15-20	"	-	-
"	145130	1	11	70 24.0	147 10.0	0	Swim	310	Medium	6	Transect	Optional*	15-20	"	-	-
7 Sep	113035	2	999	70 34.7	148 36.1	0	Swim	330	Slow	-	Search	Yes	15-20	"	-	-
8 Sep	110940	2	1	70 56.6	149 20.0	1	Swim	100	Medium	2	Transect	No	40-45	"	-	-
"	123440	1	7	70 51.6	148 02.0	0	Swim	270	Slow	4	Transect	No	50-55	"	-	-
9 Sep	104010	1	1	70 40.5	149 20.0	0	Swim	90	Medium	4	Transect	No	10-15	"	-	-
"	105825	1	2	70 48.9	149 07.1	0	Rest	80	None	2	Transect	No	30-35	"	-	-
"	121000	1	105	70 34.8	148 34.5	0	Breach	-	Breach	3	Transect	No	15-20	"	-	-
"	121205	2	105	70 38.7	148 34.5	0	Swim	270	Medium	3	Transect	No	20-25	"	-	-
"	145742	1	6	70 32.4	148 15.0	0	Surge	270	Fast	5	Transect	Optional*	10-15	"	-	-
"	165635	1	11	70 26.0	147 09.8	0	Rest	270	None	2	Transect	Optional**	15-20	Full	73.5	100
10 Sep	100145	1	0	70 53.8	149 33.0	0	Swim	330	Slow	2	Transect	No	30-35	Full	44.6	328
"	120926	1	5	70 41.8	148 28.0	0	Swim	300	Medium	1	Transect	No	25-30	Full	23.8	43
"	155000	1	9	70 56.0	147 36.1	0	Rest	40	None	0	Transect	No	60-65	Full	61.8	49
13 Sep	121043	1	-1	70 54.4	149 46.0	0	Swim	280	Slow	0	Transect	No	30-35	None	-	-
"	123530	1	0	70 51.7	149 32.9	0	Swim	300	Slow	0	Transect	No	25-30	"	-	-
15 Sep	101729	1	-4	70 43.1	150 25.5	0	Swim	330	Slow	3	Transect	No	0-5	Partial	42.0	293
"	113830	1	-1	70 46.0	149 44.9	0	Rest	180	None	3	Transect	No	15-20	Partial	24.3	323
17 Sep	112421	1	999	71 05.8	150 15.9	0	Rest	180	None	-	Search	Yes	45-50	Full	67.5	329

Continued...

TABLE 5.3. Concluded.

Date	Time	No. Bhds.	Trans. No.	Lat.	Long.	No. Calves	Behav.	Orient. (Deg. T)	Swim Speed	Beaufort Scale	Sighting Type	Exclus. From Anal.*	Km from Shore Band	Seismic State	Km From Source	Bearing (Deg. T) From Source
18 Sep	140321	1	-4	70 51.7	150 25.2	0	Swim	250	Slow	1	Transect	No	15-20	Full	47.3	314
"	150310	1	-1	70 50.4	149 46.0	0	Swim	90	Slow	1	Transect	No	20-25	Full	26.6	339
"	155928	2	2	70 43.1	149 06.9	0	Swim	100	Slow	2	Transect	No	20-25	Post***	20.8	34
"	155931	1	2	70 43.2	149 06.9	0	Swim	260	Medium	2	Transect	No	20-25	Post***	21.0	34
"	164615	3	4	70 39.2	148 40.7	0	Swim	90	Medium	1	Transect	No	20-25	Post***	29.6	71
"	164616	1	4	70 39.3	148 40.7	0	Swim	90	Medium	1	Transect	No	20-25	Post***	29.7	70
"	172704	1	6	70 40.3	148 15.0	0	Swim	90	Slow	0	Transect	No	25-30	Post***	45.3	75
"	174140	1	7	70 35.8	148 02.4	0	Swim	330	Medium	0	Transect	No	20-25	Post***	51.6	87
"	181200	2	9	70 29.5	147 36.0	0	Rest	-	None	0	Transect	No	15-20	Post***	68.3	98
"	184505	1	101	70 48.9	149 26.0	0	Rest	320	None	1	Transect	No	25-30	Post***	28.0	0
19 Sep	124010	1	1	70 39.5	149 20.0	0	Swim	270	Slow	0	Transect	No	10-15	None	-	-
"	130100	2	2	70 41.6	149 04.1	0	Swim	270	Medium	0	Search	Yes	15-20	"	-	-
"	125304	3	2	70 42.7	149 07.0	0	Swim	270	Slow	0	Transect	Optional**	20-25	"	-	-
"	131645	2	3	70 54.4	148 54.0	0	Swim	310	Slow	0	Transect	No	40-45	"	-	-
"	163337	5	6	70 37.6	148 14.7	0	Swim/dive	350	Slow	0	Transect	No	20-25	"	-	-
"	163349	1	6	70 38.0	148 14.6	0	Fluking	350	Incr. speed	0	Transect	No	20-25	"	-	-
"	170056	1	7	70 43.8	148 02.1	0	Rest	180	None	0	Transect	No	35-40	"	-	-
	171145	1	8	70 34.0	147 49.0	0	Rest	340	None	1	Transect	No	20-25	"	-	-
"	172140	1	8	70 51.5	147 48.9	0	Rest	300	None	0	Transect	No	50-55	"	-	-
20 Sep	111427	1	3	71 14.3	148 45.3	0	Rest	180	None	0	Connect	Yes	75-80	"	-	-
"	121328	1	6	70 45.0	148 15.0	0	Rest	225	Slow	0	Transect	No	35-40	"	-	-
"	123805	1	7	70 37.9	148 02.0	0	Rest	270	None	0	Transect	No	25-30	"	-	-
"	123805	1	7	70 37.9	148 02.0	0	Rest	135	None	0	Transect	No	25-30	"	-	-
"	134743	2	11	70 56.8	147 09.3	0	Swim	315	Slow	0	Transect	No	70-75	"	-	-
"	135527	1	11	70 39.7	147 10.1	0	Swim/dive	310	Medium	1	Transect	No	40-45	"	-	-
"	135638	2	11	70 37.6	147 10.1	0	Unknown	320	Slow	0	Transect	No	35-40	"	-	-
"	143705	1	4	70 39.0	148 40.9	0	Swim	300	Slow	2	Transect	No	15-20	"	-	-
"	144923	1	3	70 38.2	148 53.42	0	Swim	280	Slow	2	Transect	No	15-20	"	-	-
"	184250	1	-1	71 00.3	149 46.0	0	Swim	90	Medium	2	Transect	No	40-45	"	-	-

* Transect sightings (and associated effort) during Beaufort state 5+ and/or seriously impaired visibility conditions were excluded from some analyses. "Search" and "Connect" sightings were excluded from all analyses.

** Transect sightings during period of seriously impaired visibility (e.g. fog, snow showers), excluded from some analyses.

*** Distance and bearing are calculated from position of the source vessel when it ceased shooting full seismic at 15:48:05 on 18 September.

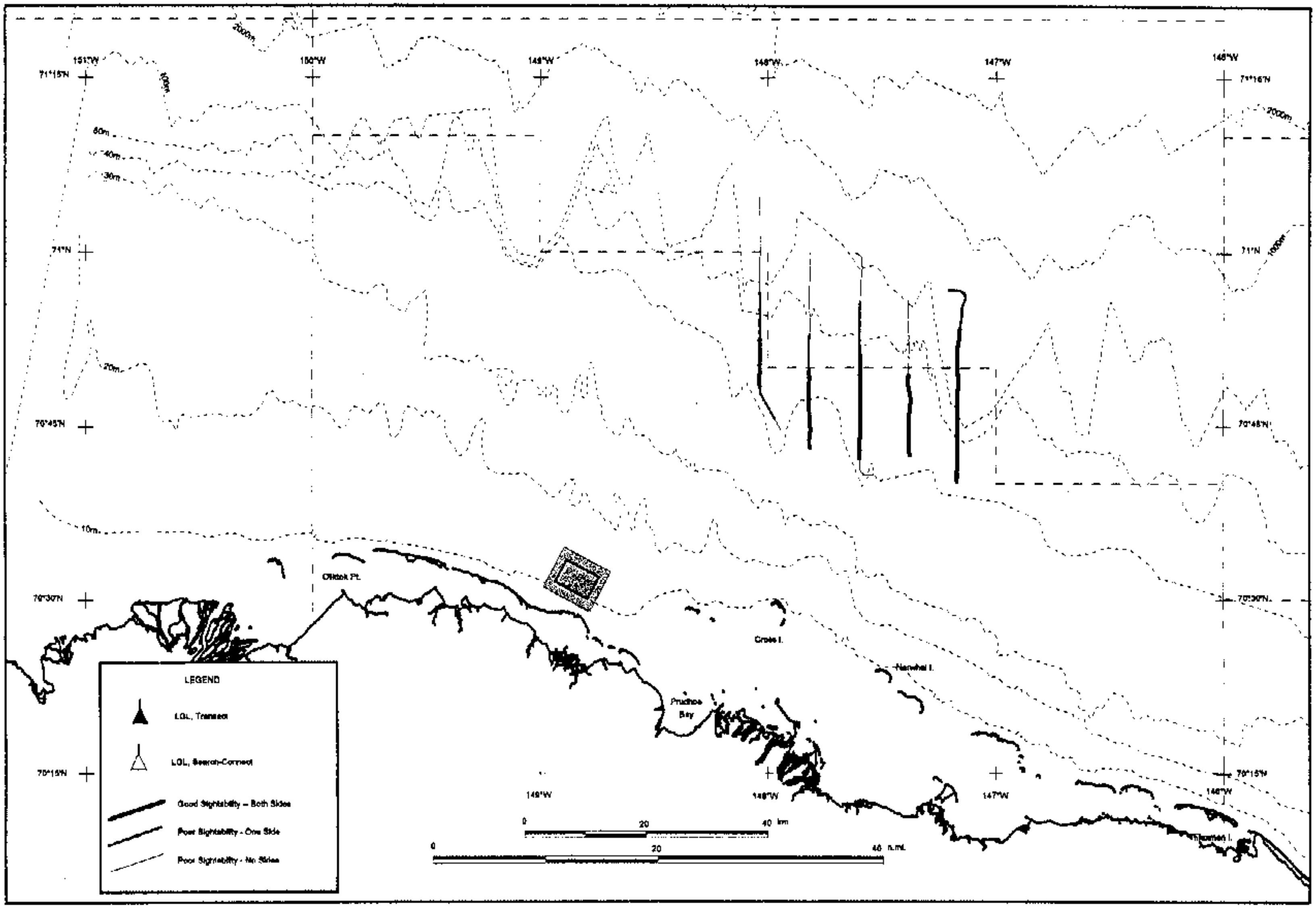

FIGURE 5.8. Aerial survey coverage of the extensive grid, 3 September 1996. Low cloud prevented surveys of much of the extensive grid and all of the intensive grid. No bowheads were sighted. The area where the source vessel was shooting full array seismic is shaded.

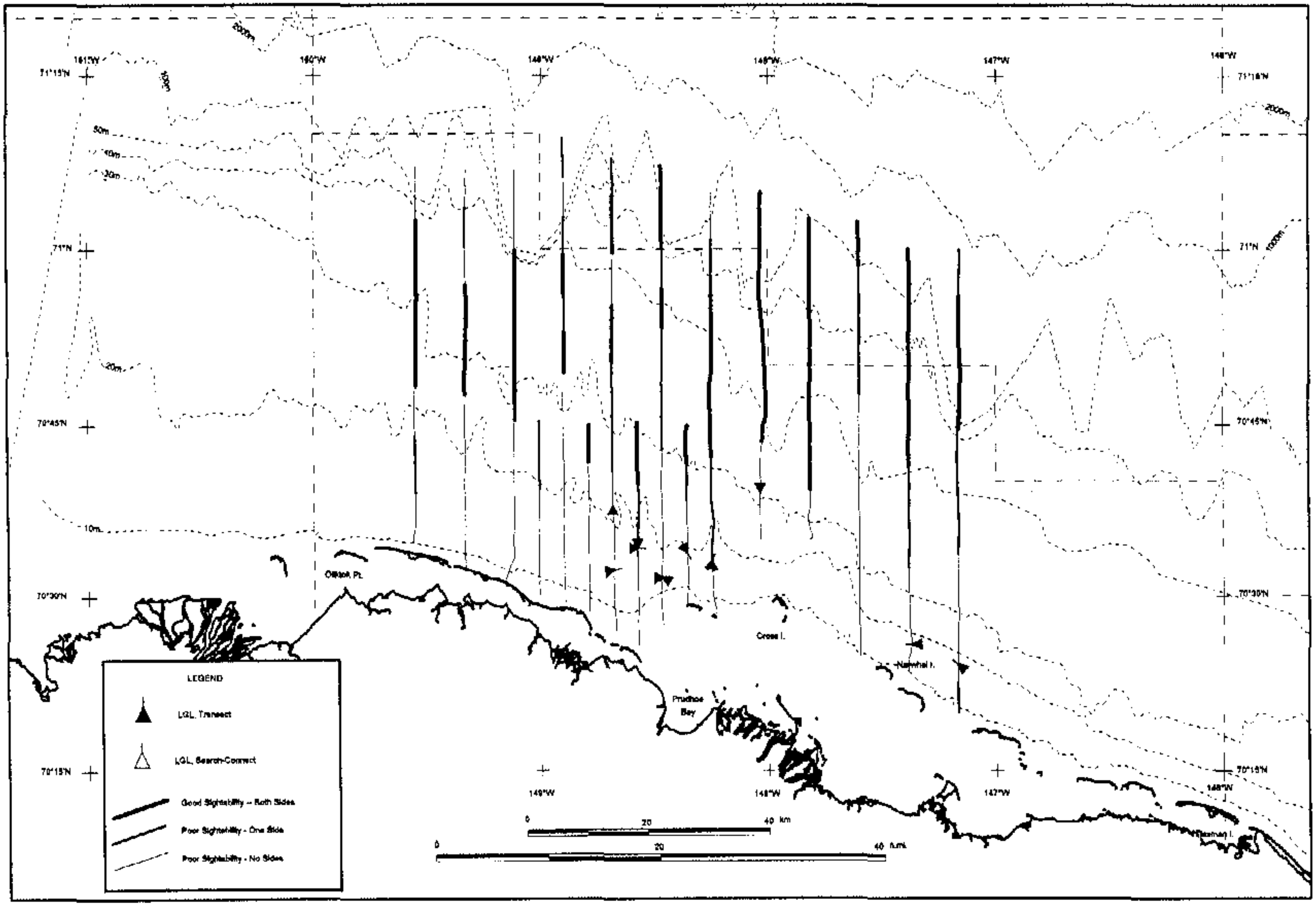

FIGURE 5.9. Aerial survey coverage of the extensive and intensive survey grids, 5 September 1996. A total of 14 bowheads were sighted. There were no airgun operations during this survey.

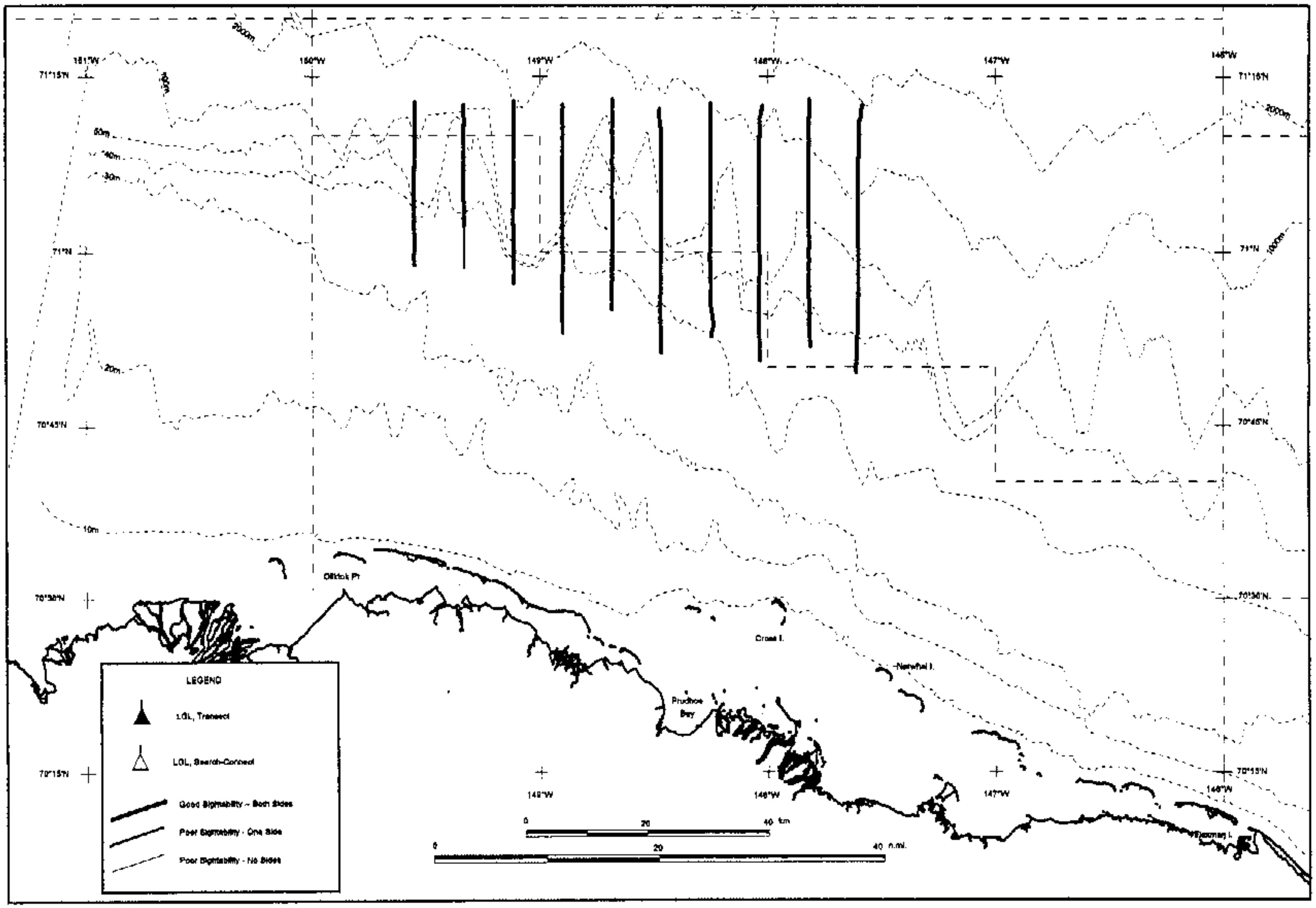

FIGURE 5.10. Aerial survey coverage of the extensive grid, 6 September 1996. Persistent fog prevented surveys of the southern part of the study area. Transects 2-9 were extended farther offshore than usual. No bowheads were sighted. There were no airgun operations during this survey.

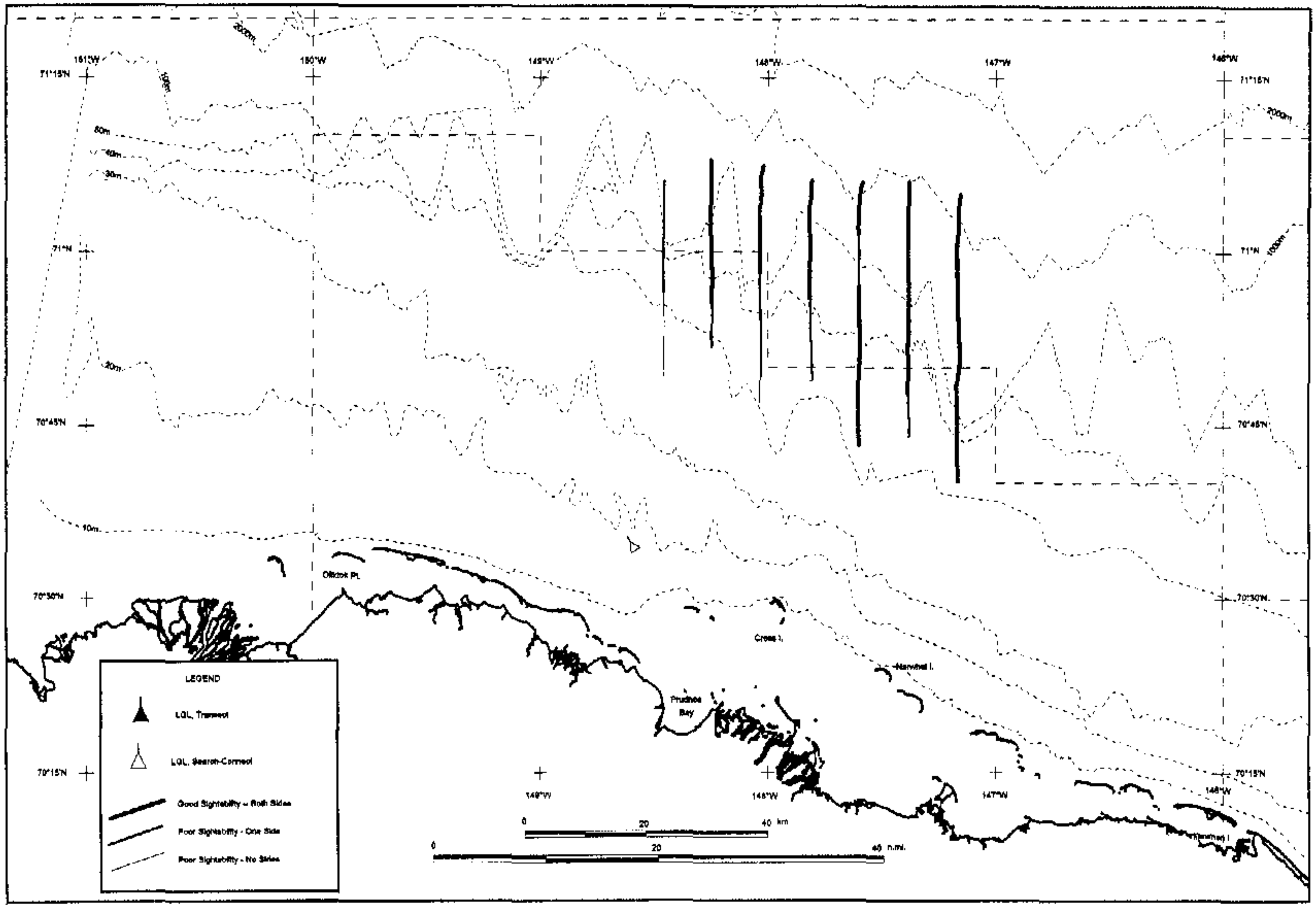

FIGURE 5.11. Aerial survey coverage of the extensive grid, 7 September 1996. Low cloud prevented surveys of much of the extensive grid and all of the intensive grid. Transects that were surveyed were extended north beyond the standard northern endpoints. Two bowheads were sighted incidentally during the return flight to Deadhorse. There were no airgun operations during this survey.

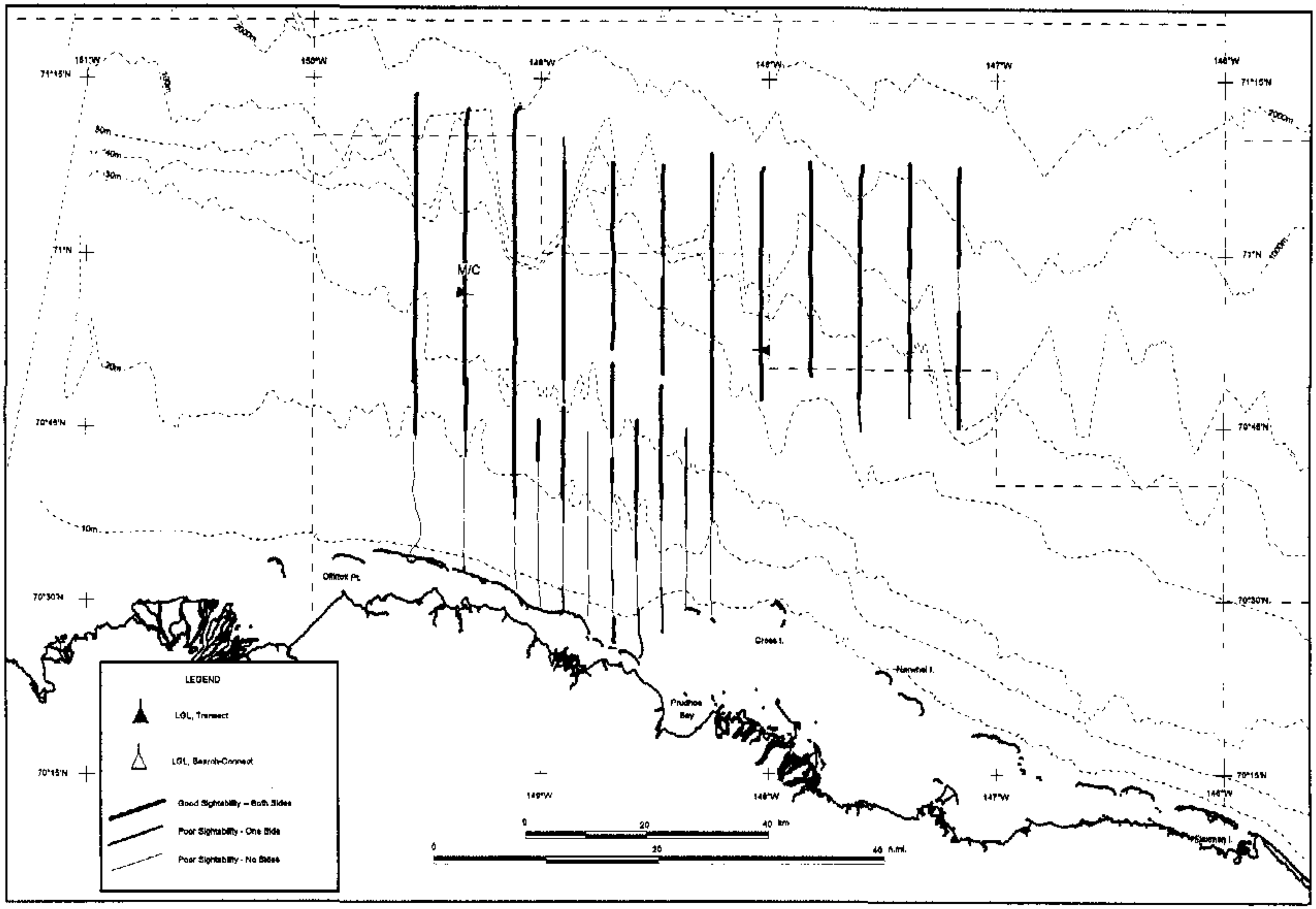

FIGURE 5.12. Aerial survey coverage of the extensive and intensive grids, 8 September 1996. Three bowheads including a mother-calf pair (M/C) were sighted. Low cloud prevented surveys of the southeastern portion of the extensive grid. There were no airgun operations during this survey.

with full array seismic (313.2 km). Although some single airgun seismic was shot on this date, it occurred during the period between the two survey flights, not during the surveys. Six sightings including a total of 7 bowheads were recorded. One sighting was in an area with a high sea state (Table 5.3). The sightings were widely distributed throughout the survey grids in both nearshore and offshore waters (Fig. 5.13). Five sightings of 6 bowheads occurred during periods with no seismic. A single bowhead was sighted 73.5 km east of the seismic vessel during the full array seismic period; it was resting at the surface (Table 5.3).

Complete survey coverage was also obtained on 10 September (972 km). All transects were surveyed while full array seismic was underway (Table 5.2). The three bowheads sighted were widely distributed throughout the survey area (Fig. 5.14). The closest whale to the active seismic vessel was 24 km to the NE and was traveling at medium speed to the WNW (Table 5.3). This was one of the two closest sightings to the operating seismic vessel during the project, although there were two slightly closer sightings on 18 September only 11.4 min after the end of a period of full-array seismic.

By 13 September, the seismic operations moved farther west. The aerial survey grids were shifted to the west on this date. The westernmost line in the extensive grid was now line -4 at longitude 150°25' W; previously, the westernmost survey line had been line 0 at 149°33'W. The westernmost line in the intensive grid was now line 100 at 149°40'W (previously line 103 at 149°01'W) (Fig. 5.15). Mechanical problems with the survey aircraft restricted the survey coverage to 6 transects (426 km) in the extensive grid (Table 5.2). Two bowheads were sighted during the "no seismic" condition that prevailed throughout the survey.

On 14 September the survey flight was curtailed after only two extensive transects had been surveyed (Fig. 5.16). Sea states were high and visibility was obscured by snow. No bowheads were seen during 145 km of surveys with full array seismic (Table 5.2).

On 15 September, 1106 km of transect surveys (extensive and intensive) were flown (Fig. 5.17). Of this coverage, 791 km were during partial array seismic (5 airguns in this case) and 315 km were during full array seismic (Table 5.2). A portion (436 km) of the surveys flown during partial array seismic occurred within 3.5 hours after a full-array seismic period (post-seismic). The 2 bowheads seen were observed during a partial array seismic period that was concurrent with this post-"full array"-seismic period. The more distant whale was 42 km WNW and swimming to the NNW. The closer whale was 24 km NW of the seismic vessel and was resting at the surface (Table 5.3). This was one of the two closest sightings to the operating seismic vessel during the project (not including two slightly closer sightings on 18 September, 11.4 min after seismic operations ended.)

On 16 September, 854 km of aerial surveys were flown in the extensive and intensive grids under "no seismic" conditions (Fig. 5.18; Table 5.2). Despite excellent sighting conditions, no bowheads were seen.

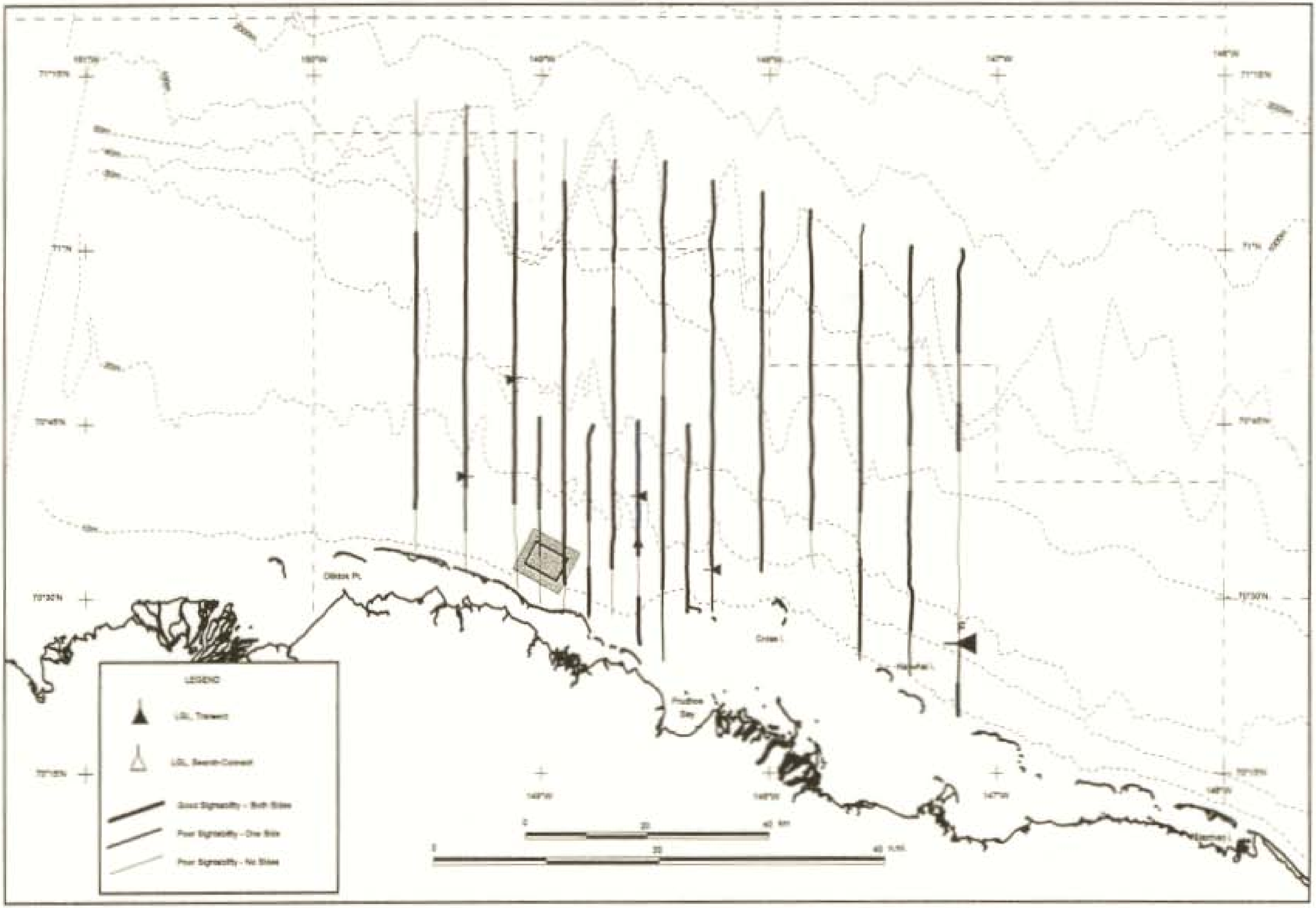

FIGURE 5.13. Aerial survey coverage of the extensive and intensive grids, 9 September 1996. Low cloud prevented surveys of the southeastern portion of the extensive grid. Seven bowheads were sighted. The large symbol with an "F" indicates the location of a bowhead sighting during full array seismic. The area where the source vessel was shooting full array seismic during part of the aerial survey is shaded.

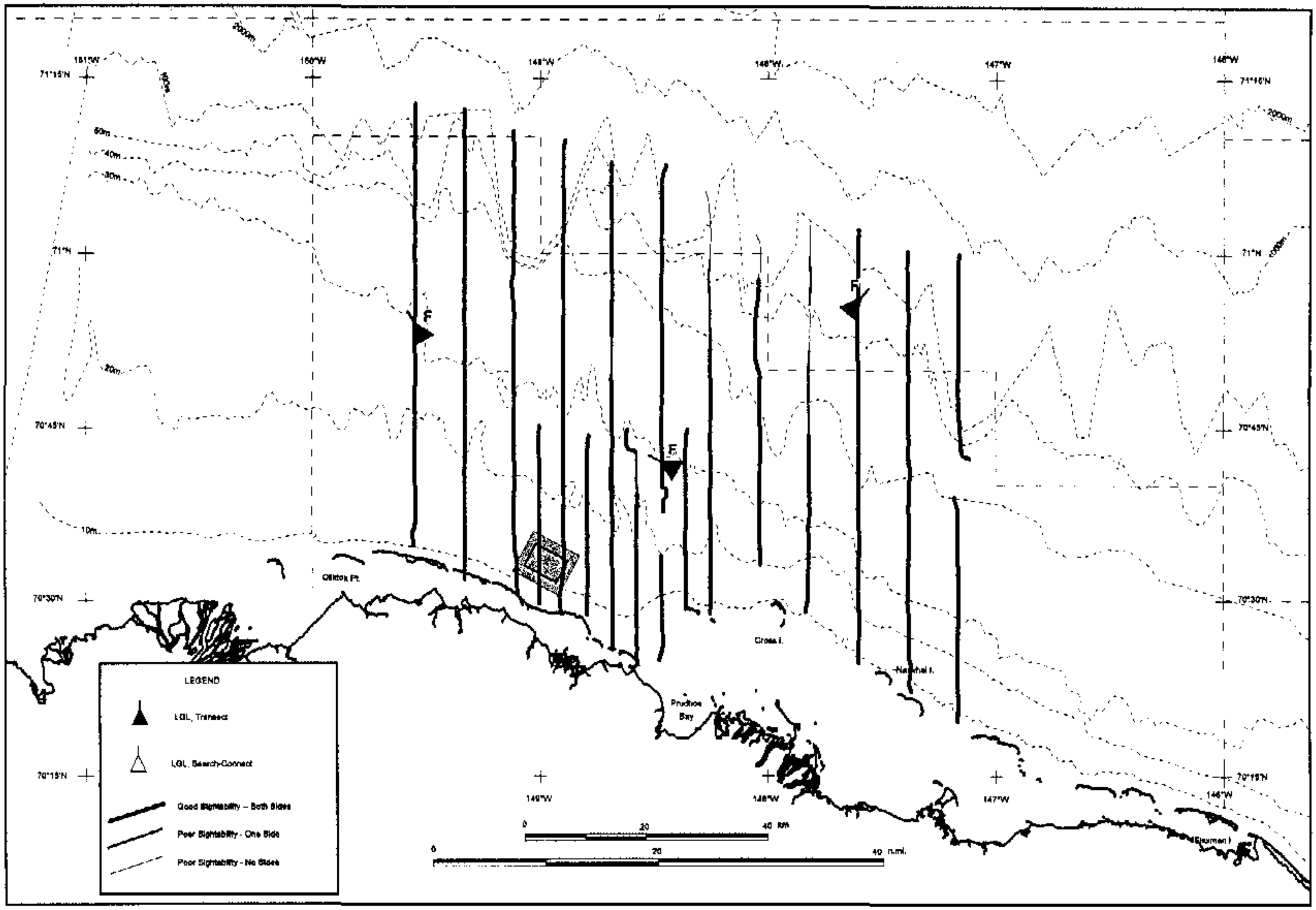

FIGURE 5.14. Aerial survey coverage of the extensive and intensive grids, 10 September 1996. Three bowheads were sighted (large symbols with an "F"). The area where the source vessel was shooting full array seismic is shaded. The southern end of survey line 7 near Cross Isl. was not surveyed in an attempt to avoid over-flying whalers, who were hunting in the survey area.

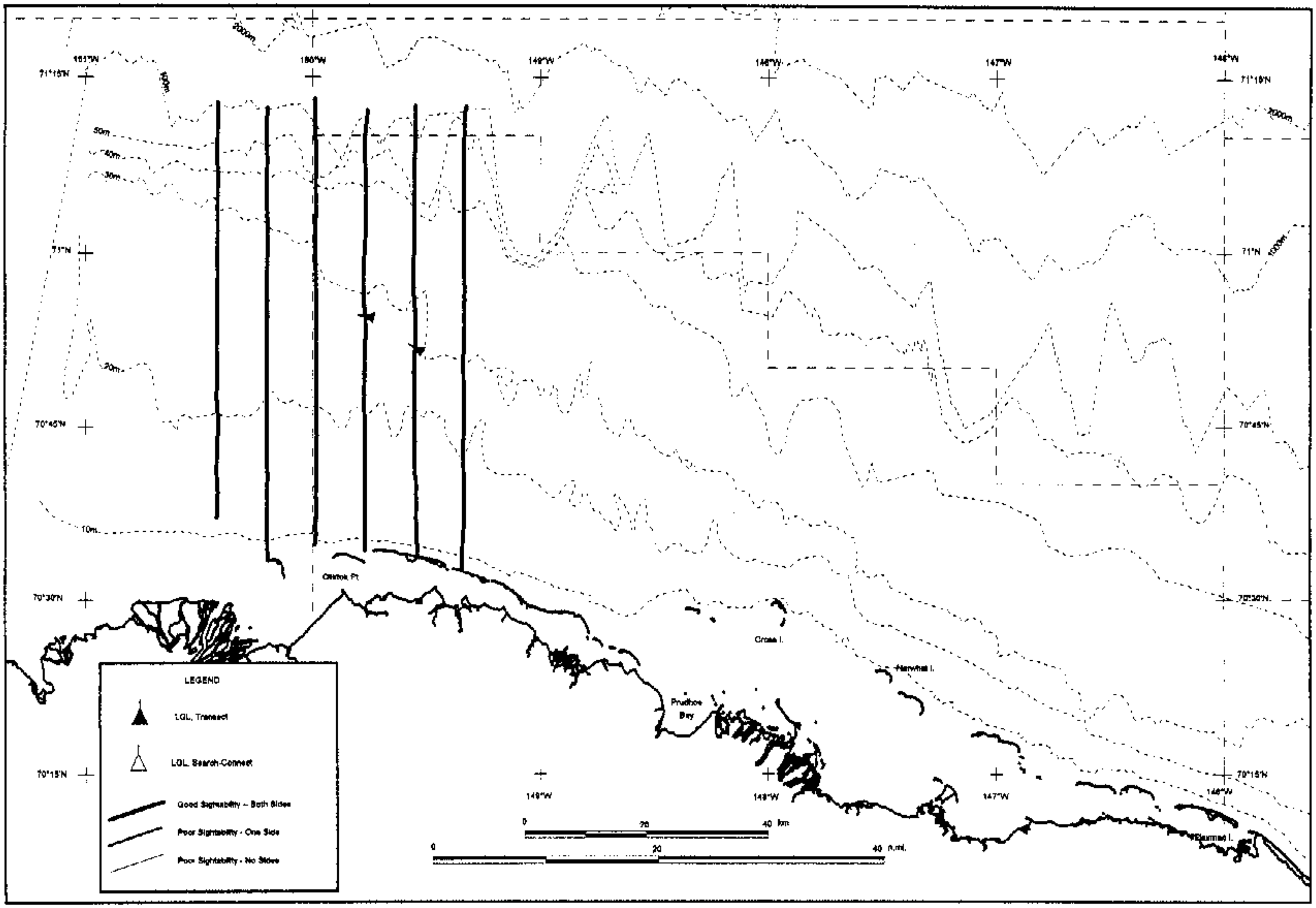

FIGURE 5.15. Aerial survey coverage of the extensive grid, 13 September 1996. The survey grid was shifted west in response to a change in the location of the seismic operations. A mis-firing aircraft engine forced an early end to the day's surveys. Two bowheads were sighted. There were no airgun operations during this survey.

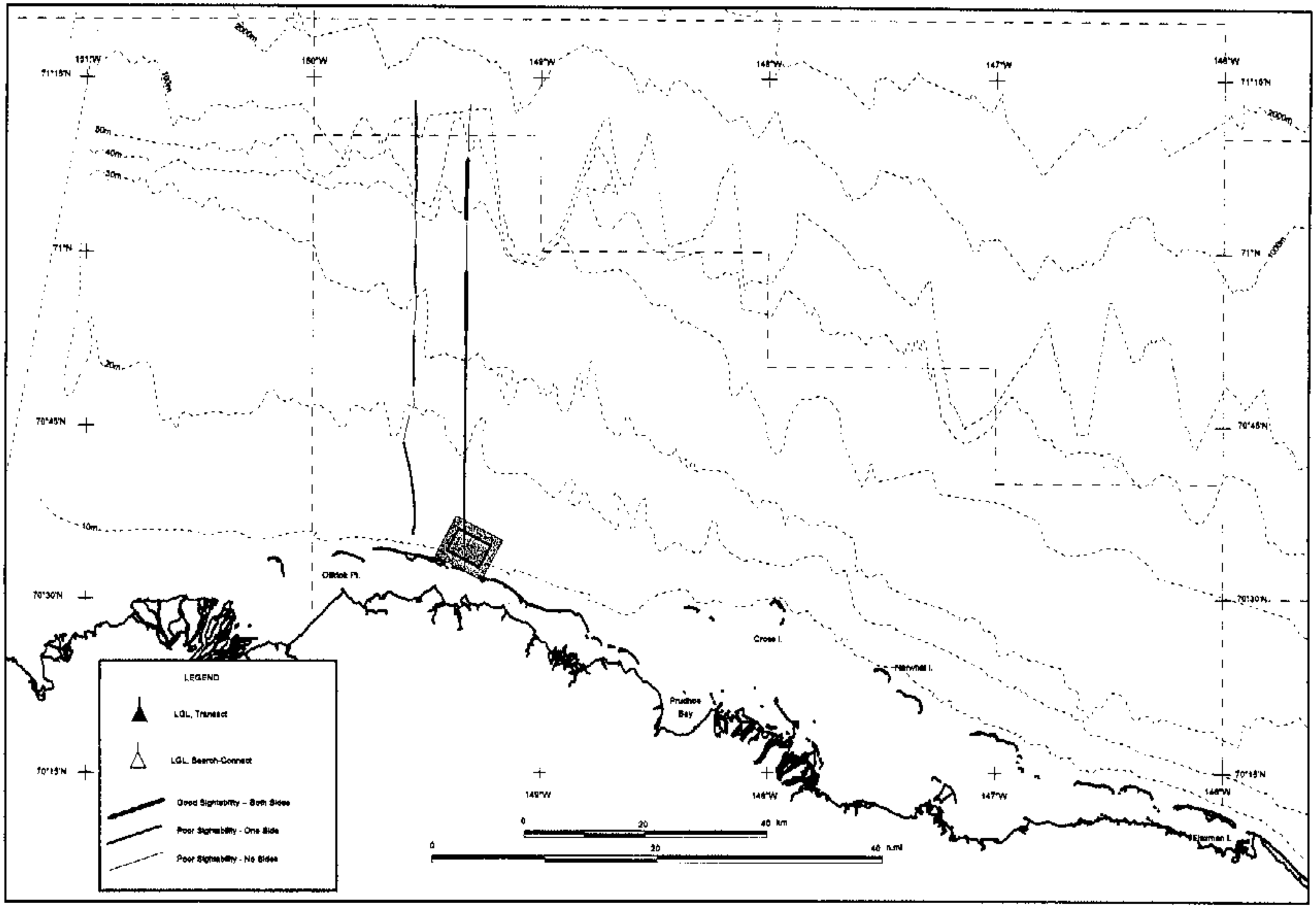

FIGURE 5.16. Aerial survey coverage of the extensive grid, 14 September 1996. Poor weather conditions, including high sea states and blowing snow, forced early termination. No bowheads were sighted. The area where the source vessel was shooting full array seismic is shaded.

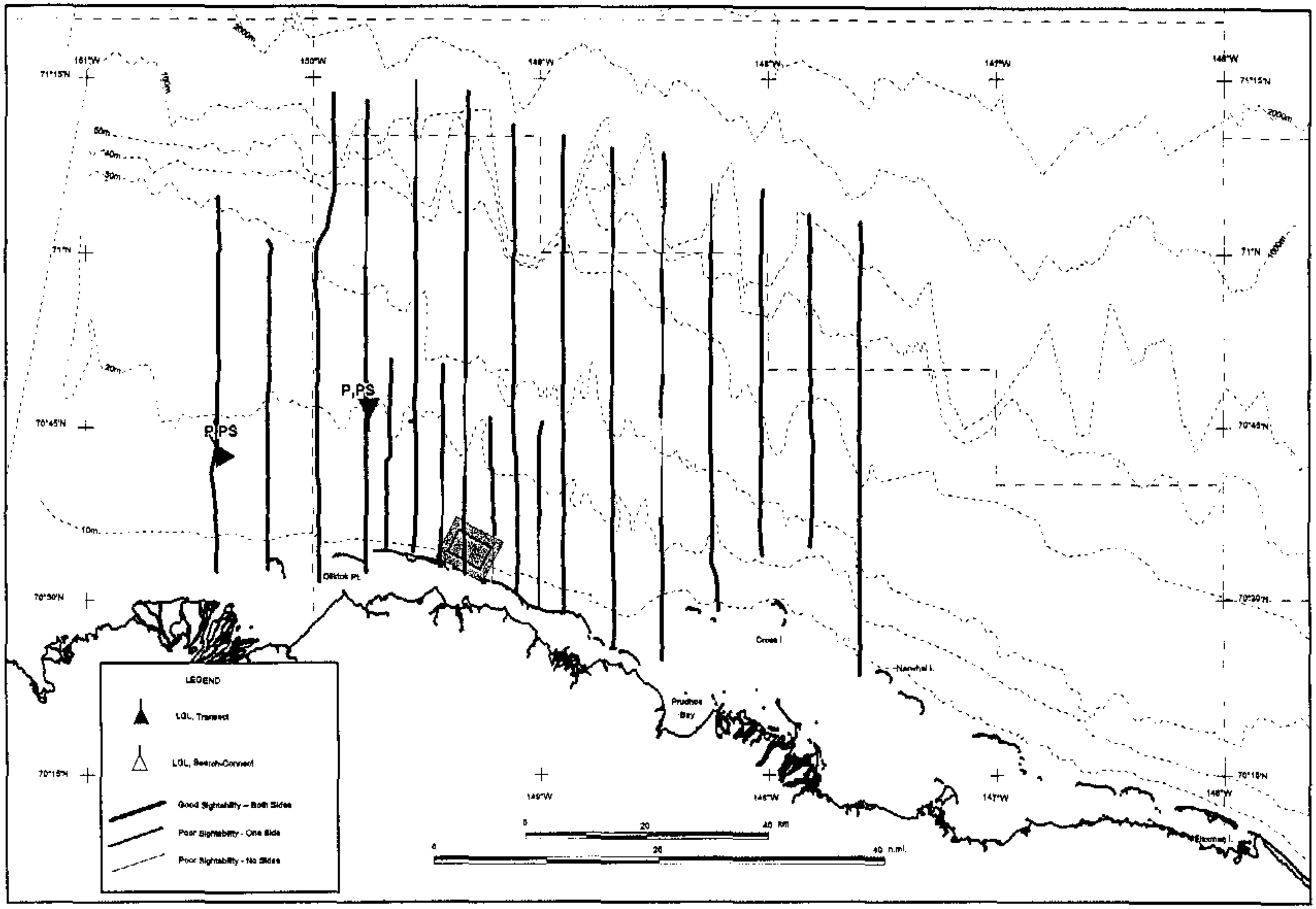

FIGURE 5.17. Aerial survey coverage of the extensive and intensive grids, 15 September 1996. Parts of some transects were obscured by snow showers. Two bowheads were sighted during partial array seismic (P) <3.5 h after a lengthy period of full array seismic (PS). The area where the source vessel was shooting partial and full array seismic is shaded. The southern ends of survey lines 7 and 8 near Cross Isl. were not surveyed in an attempt to avoid over-flying whalers, who struck and killed a bowhead east of Cross Isl. during the aerial survey.

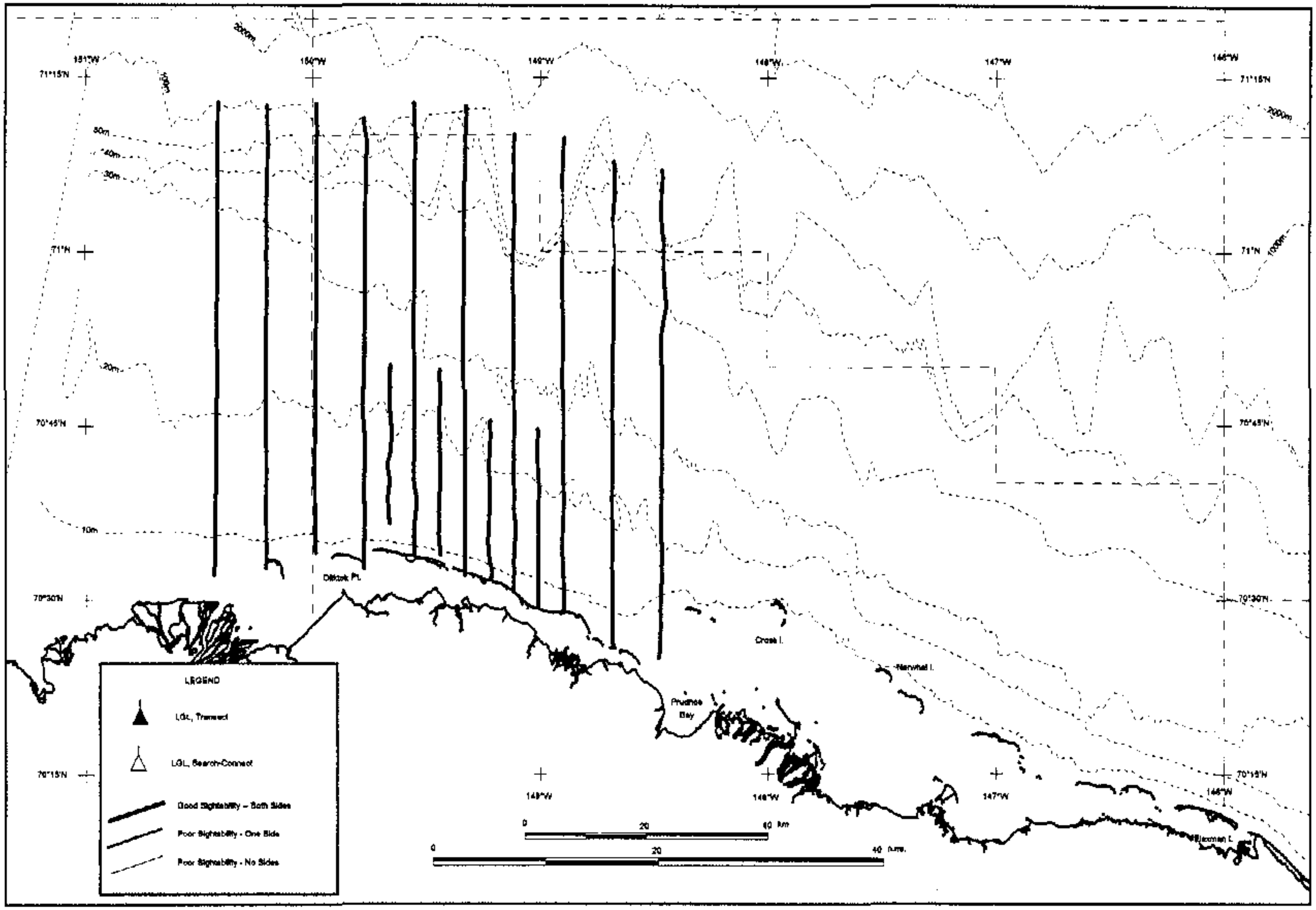

FIGURE 5.18. Aerial survey coverage of the extensive and intensive grids, 16 September 1996. Low ceilings and fog prevented surveys of the extensive grid east of transect 5. No bowheads were sighted, despite excellent sighting conditions in the areas surveyed. There were no airgun operations during this survey.

On 17 September, a single bowhead was sighted incidentally although no survey transects were flown because of a low cloud ceiling. The sighting was near the north end of transect -3 (Fig. 5.19). Full array seismic was underway at the time. The whale was 68 km NNW of the seismic vessel and was resting at the surface (Table 5.3).

On 18 September, 14 bowheads were recorded during 875 km of surveys in the extensive and intensive grids. Fog and/or snow restricted visibility at the northern ends of many transects (Fig. 5.19). The surveys were flown during periods of full array seismic (349 km) and post-seismic (525 km). Two bowheads were seen during the full array period. Twelve bowheads were seen during the post-seismic period, including two sightings (3 whales) only 11.4 min after seismic ended. Sightings during both periods were aligned along a well-defined corridor 20 to 30 km from shore. The closest whale seen during full-array seismic was 27 km NNW of the seismic vessel and was travelling slowly to the east (Table 5.3). The two sightings 11.4 min after seismic ended were about 21 km NE of the seismic vessel, swimming east (2 whales) and west (1 whale) (Table 5.3).

The source vessel finished shooting seismic on the afternoon of 18 September. Thus, aerial surveys on 19 and 20 September were conducted during periods of no seismic. On 19 and 20 September, survey coverage of the extensive and intensive grids totalled 1128 and 1189 km, respectively. Seventeen bowheads were observed on 19 September and 12 were seen on 20 September (Fig. 5.20, 5.21). On both days there were sightings in both offshore and nearshore areas.

Summary of Northstar Surveys.—Overall, during the 1-21 September 1996 study period, 10,225 km of transect surveys were flown. Of this coverage, 6648.3 km was during periods with no seismic and 3576.2 km was during periods potentially influenced by seismic activities: 791.3 km during partial array seismic (all of it with five airguns), 2259.4 km during full array seismic, and 525.5 km during post-seismic periods (i.e. within 3.5 hours after the end of full array seismic).

In total, during BPXA/LGL surveys from 1 to 21 September there were 58 sightings of bowheads involving 77 individuals. Of these,

- 7 sightings and 7 individuals were with full array seismic,
- 2 sightings and 2 individuals were with partial array seismic (and within 3.5 h after the end of full-array seismic),
- 8 sightings and 12 individuals were during post-seismic periods, and
- 41 sightings and 56 individuals were during no-seismic periods.

There was no immediately obvious relationship between the numbers of bowheads sighted and the status of the seismic array during the aerial surveys (Fig. 5.22). Relatively large numbers of bowheads were seen during days with seismic (18 September) and without seismic (5 Sep.). Likewise, few bowheads were recorded on other days with seismic (10 Sep.) and without seismic (16 Sep.).

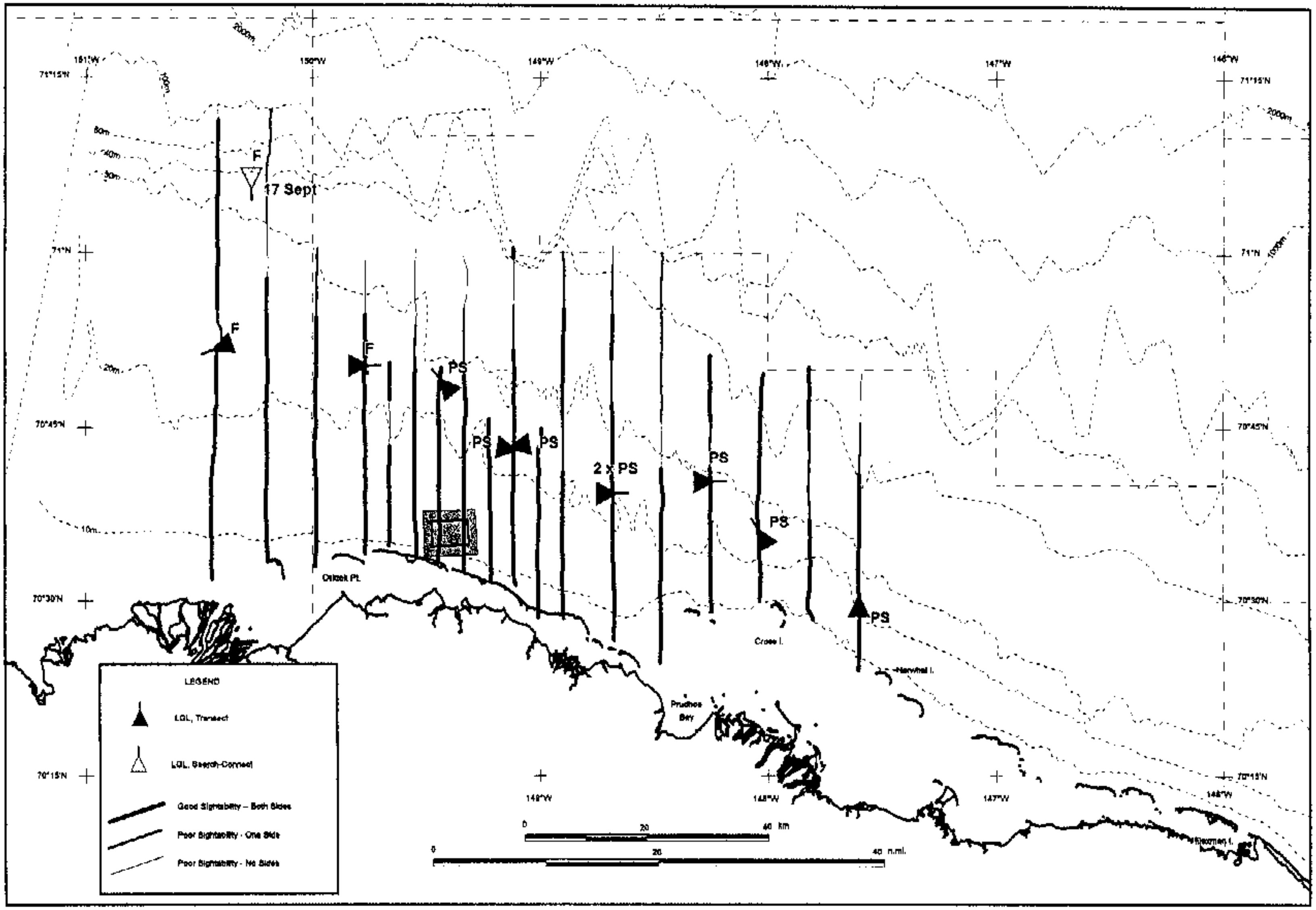

FIGURE 5.19 Aerial survey coverage of the extensive and intensive grids, 18 September 1996. Fog and/or snow obscured the northern portions of many extensive lines. Fourteen bowheads were sighted during full array (F) and post-seismic (PS) periods. (The location of a single incidental sighting from 17 September is also plotted here.) The area where the source vessel was shooting full array seismic on both 17 and 18 September is shaded.

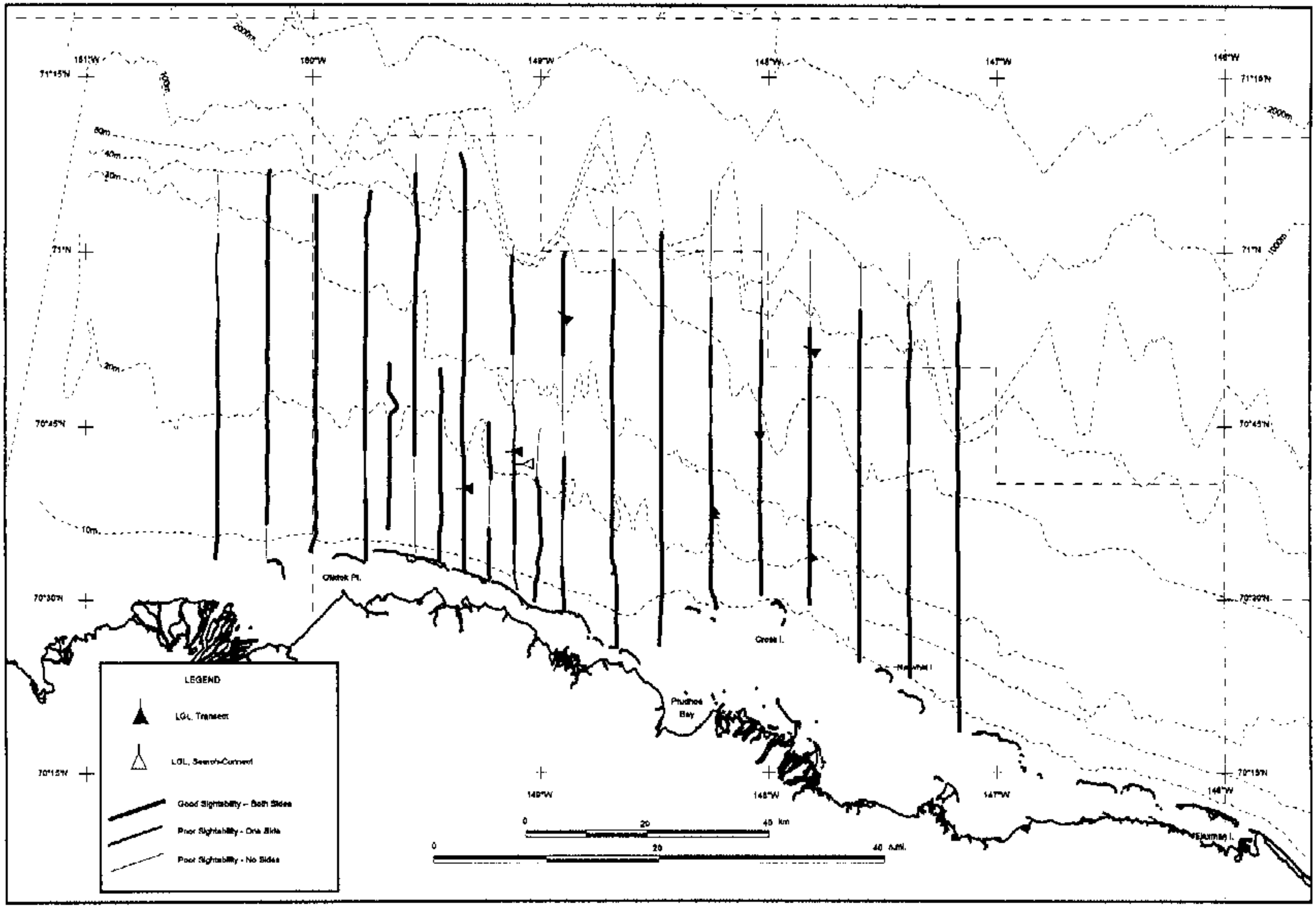

FIGURE 5.20. Aerial survey coverage of the extensive and intensive grids, 19 September 1996. The northern ends and some other portions of many transects had reduced visibility due to fog and/or snow. A total of 17 bowheads were sighted. Airgun operations had ended for the season on 18 September.

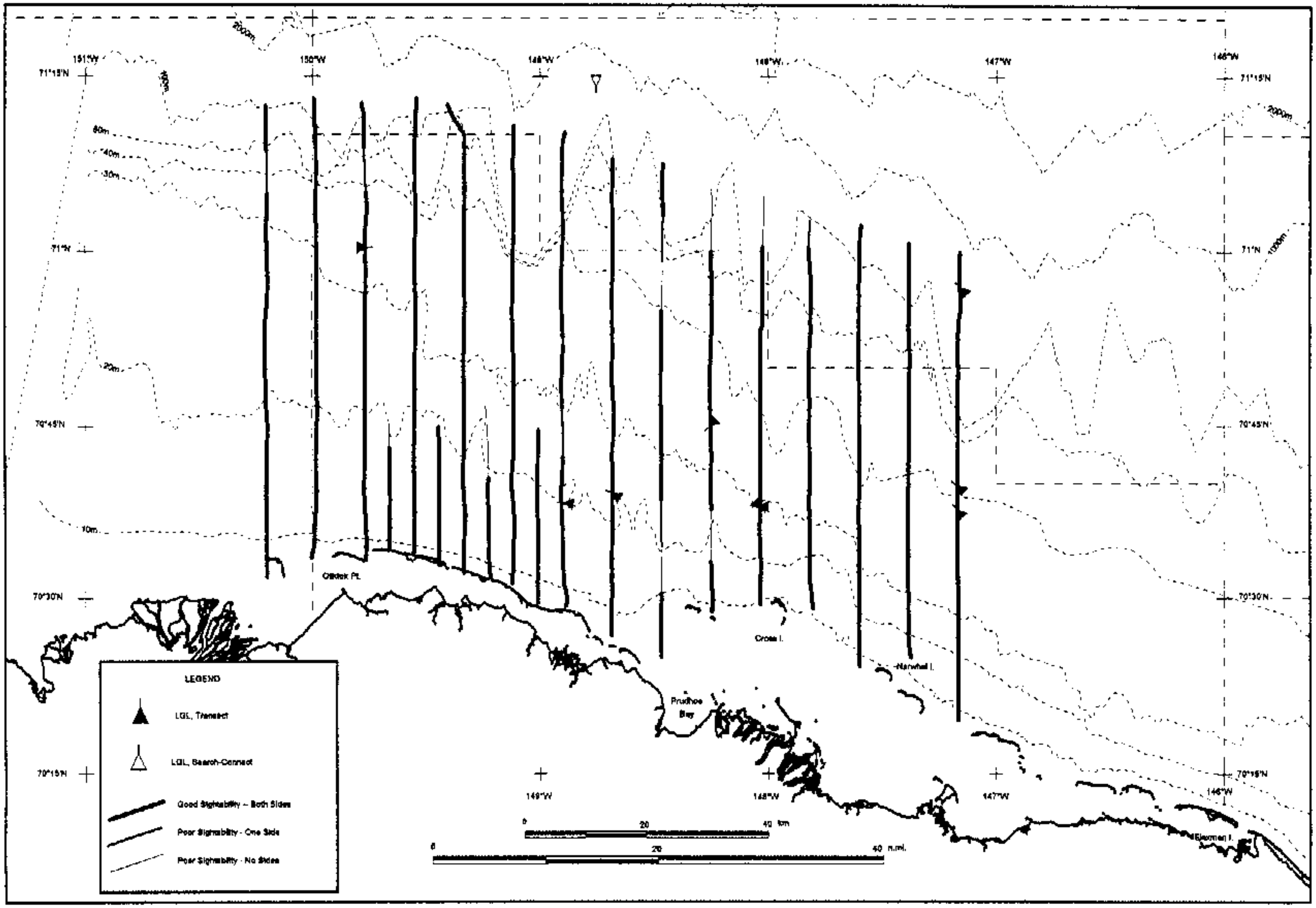

FIGURE 5.21. Aerial survey coverage of the extensive and intensive grids, 20 September 1996. Twelve bowheads were sighted. Airgun operations had ended for the season on 18 September.

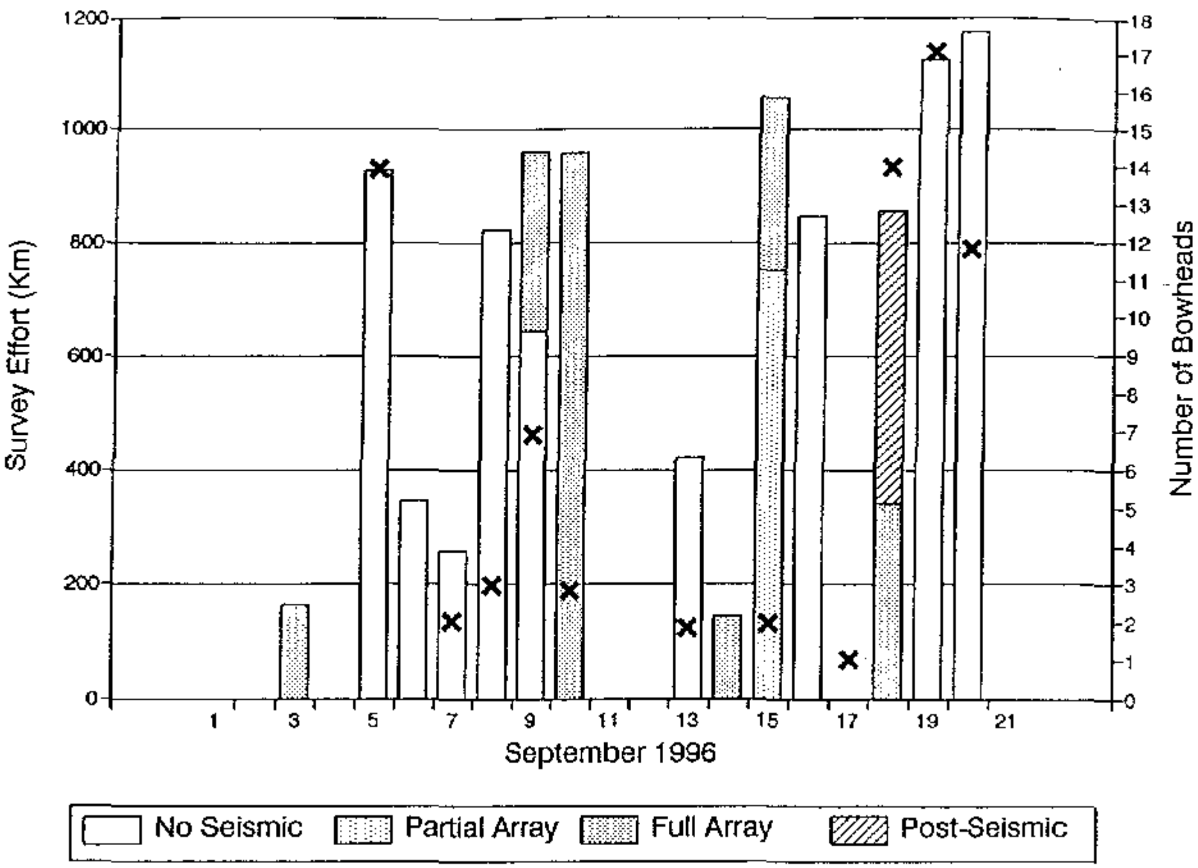

FIGURE 5.22. BPXA/LGL aerial survey coverage (bars) and the number of bowheads seen (X) in the Northstar region during each day of LGL aerial surveys, 1-21 September 1996. Shading of bars shows the amount of aerial survey coverage with various categories of seismic operations.

Overall, we saw an average of 0.59 bowheads per 100 km of surveys during all seismic conditions combined (n=17 sightings and 21 individuals), and 0.84 bowheads per 100 km of surveys without seismic (n=41 and 56). The sighting rates under partial, full, and post-seismic conditions were highly variable but based on low sample sizes: 0.25 bowheads/100 km with partial array seismic (n=2 sightings and 2 individuals), 0.31 with full array seismic (n=7 and 7), and 2.28 under post-seismic conditions (n=8 and 12).

5.3.2 Distribution

LGL Sightings.—All of LGL's bowhead sightings during the 1996 Northstar monitoring program are shown in Figure 5.23. Nearly all were found in relatively nearshore waters, mainly between the 15 m and 40 m depth contours, approximately 10 to 50 km from shore. This was true during periods both with seismic exploration (large symbols) and without seismic (small symbols). Only six sightings occurred seaward of the 40 m depth contour, with four being between the 40 and 100 m contours, and two being north of the 100 m contour (Fig. 5.23). Only one of the six sightings beyond the 40 m contour occurred during a full array, partial array or post-seismic period.

In the Northstar area proper (west and northwest of Cross Island) the sightings closest to shore were all recorded during periods without seismic activity (Fig. 5.23). It is possible that this was related to the occurrence of seismic work. However, there was more survey effort at times without than at times with seismic exploration (6567 vs. 3495 km of surveys, respectively). The distribution of sightings is examined further under "1996 Seismic vs. 1996 No Seismic" (p. 5-52), taking account of MMS as well as BPXA/LGL sightings.

The closest bowhead sightings to the operating airgun array were 24-27 km away (Table 5.3). If these whales were traveling WNW parallel to shore, they apparently were not at their closest points of approach when seen (Fig. 5.14, 5.17, 5.19). There were two additional bowhead sightings 21 km from the vessel 11.4 min after seismic ended (Table 5.3; Fig. 5.19). Those bowheads were presumably no more than 22 km from the seismic vessel at the end of the preceding full-array seismic period.

MMS Sightings.—The Minerals Management Service, Alaska OCS Region, conducted aerial surveys of marine mammals in the Beaufort Sea from 1 September through 9 October 1996. MMS's bowhead data have been provided by S.D. Treacy, MMS (pers. comm.).

On 13 days during the late summer and autumn of 1996, MMS conducted transect surveys in their survey block 1, block 2, and the eastern part of block 3 (east of 150°30'W). These areas include the Northstar region and the area where the BPXA/LGL surveys were conducted. MMS sighted bowheads within this area on seven dates in 1996. In total, MMS obtained 29 sightings of 39 individual bowhead whales in this area (Fig. 5.24).

None of the sightings by MMS within the 146°W-150°30'W area were during periods of active seismic exploration or during the 3.5 hour periods following termination of full array seismic operations. Twelve MMS sightings, including a total of 17 bowheads, were obtained

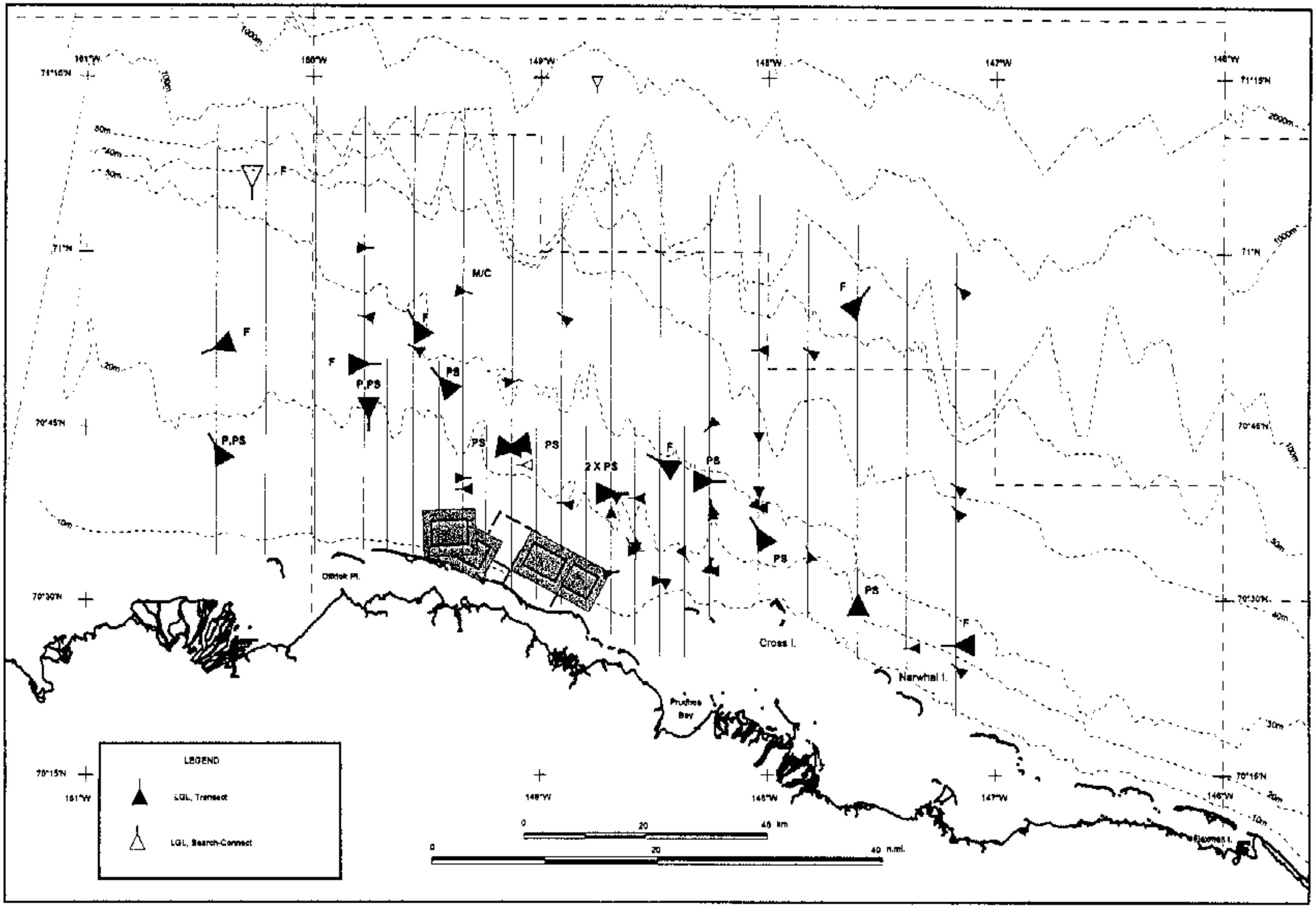

FIGURE 5.23. Bowhead whale sightings in the Northstar region of the central Alaskan Beaufort Sea during 1-21 September 1996 based on LGL aerial surveys. Nominal transect lines are shown, but only a portion of the grid was surveyed each day. All areas where the source vessel shot partial and full array seismic during September are indicated. Large symbols show sightings during "all seismic" periods. See daily sighting maps (Fig. 5.8-5.21) for the daily survey coverage and seismic vessel positions.

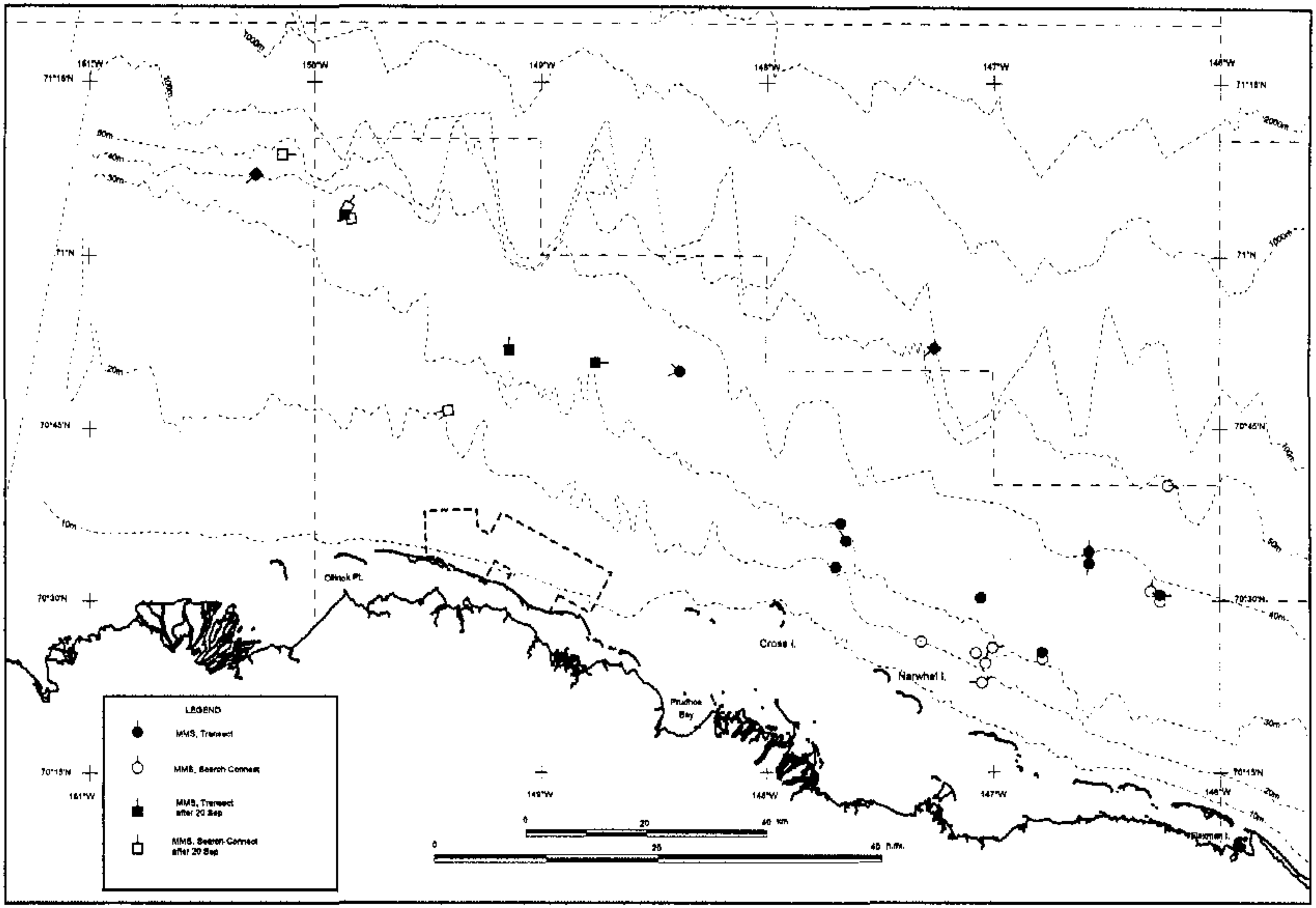

FIGURE 5.24. Bowhead whale sightings in the central Alaskan Beaufort Sea (146°-151°) during 1 September - 9 October 1996 based on MMS aerial surveys (data courtesy of S. Treacy, MMS). Sightings up to and after 20 September are distinguished. Seismic patches shot during 1-18 Sep. 1996 are outlined. All MMS sightings were during "no-seismic" periods.

prior to 18 September when seismic exploration ended. These sightings were on 2, 5 and 8 September at times 17.1-36.8 h after airgun operations had been interrupted. The remaining 17 sightings of 22 bowheads were on 19, 20, 27 and 30 September, 43 to 287 h after seismic activities were terminated for the season.

MMS's bowhead sightings in the eastern part of the study area (east of Cross Island and Northstar) tended to be closer to shore than were the MMS sightings farther west (Fig. 5.24).

Combined LGL and MMS Sightings.—The combined BPXA/LGL and MMS sightings of bowheads during late summer and autumn of 1996 are shown in Figure 5.25. In general, the MMS sightings, and especially the MMS "Transect" sightings, tended to be farther offshore than the LGL sightings. This was so even though most of MMS's transect surveys extended southward to the barrier islands (Fig. 5.3).

The combined BPXA/LGL and MMS 1996 sightings appear to be more widely dispersed, in terms of distance from shore, than the 1995 bowhead sightings (small symbols in Fig. 5.26). The 1996 sightings were recorded both farther from shore and closer to shore than 1995 sightings even though, in total, there were more sightings within the mapped area during 1995. For example, the number of sightings in "offshore waters", here defined as MMS block 2 or on the border between blocks 1 and 2, was 7 sightings in 1996 but only 1 in 1995 (Fig. 5.25 vs. 5.26). (Figure 5.2 shows MMS survey block numbers.) Likewise, the number of bowhead sightings shoreward of the 20 m contour was about 19 in 1996 compared to only 5 in 1995. Despite the broader distribution in 1996, the main clusters of sightings in the two years were along fairly similar corridors, with sightings concentrated in waters 20-50 km from shore in 1995 and 10 to 50 km from shore in 1996.

The few (nine) 1994 sightings were very broadly distributed across a wide range of depth and distance-from-shore categories (large symbols in Fig. 5.26). High proportions of these were in the offshore (3 of 9) and nearshore (4 of 9) regions described above. Thus, only two of nine 1994 sightings occurred in the medium depth waters where the great majority of both 1996 and 1995 sightings occurred.

Bowhead sightings in the Northstar region during 1979-93, years with widely varying ice and industrial activity conditions, were concentrated in water depths ranging from 10 to 100 m (Fig. 5.27). In 1979-93 there were a few sightings on or inshore of the 10 m contour, including a few within the area where seismic surveys were conducted in September 1996.

5.3.3 Distance from Shore

In this section, bowheads seen in the Northstar area in 1996 and various earlier years are plotted as a function of distance from shore, as described in §5.2, "Methods". A large number of graphs, comparisons, and statistical tests are included. Readers wishing to review just a summary of this material can skip to "Summary of Distances from Shore" on p. 5-68.

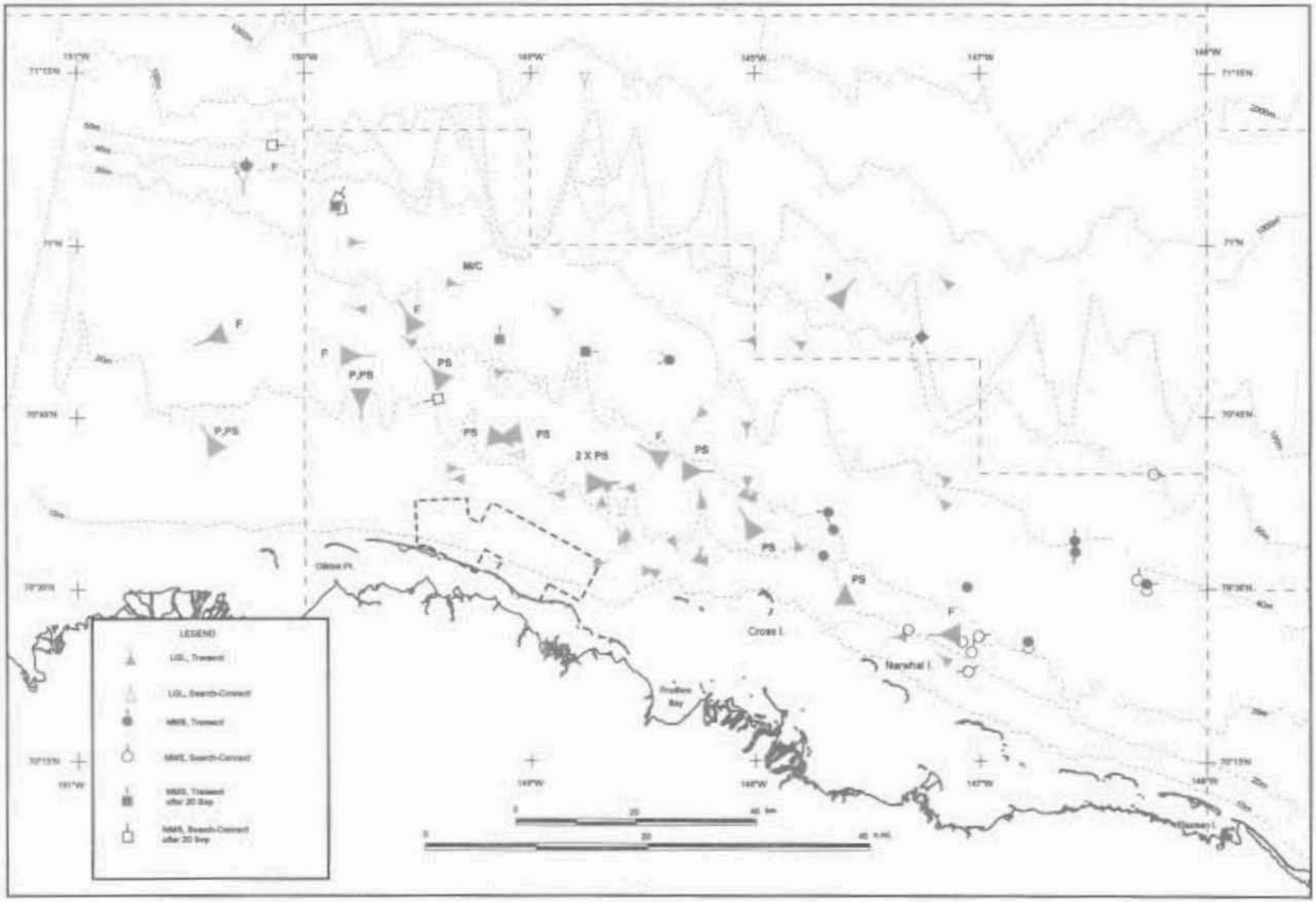

FIGURE 5.25. Bowhead whale sightings in the central Alaskan Beaufort Sea (146°-151°) during 1 September - 9 October 1996 based on LGL and MMS aerial surveys. MMS sightings up to and after 20 September are distinguished. All LGL sightings were in the 5-20 September period. Seismic patches shot during 1-18 Sep. 1996 are outlined. Large symbols show sightings during "all seismic" periods.

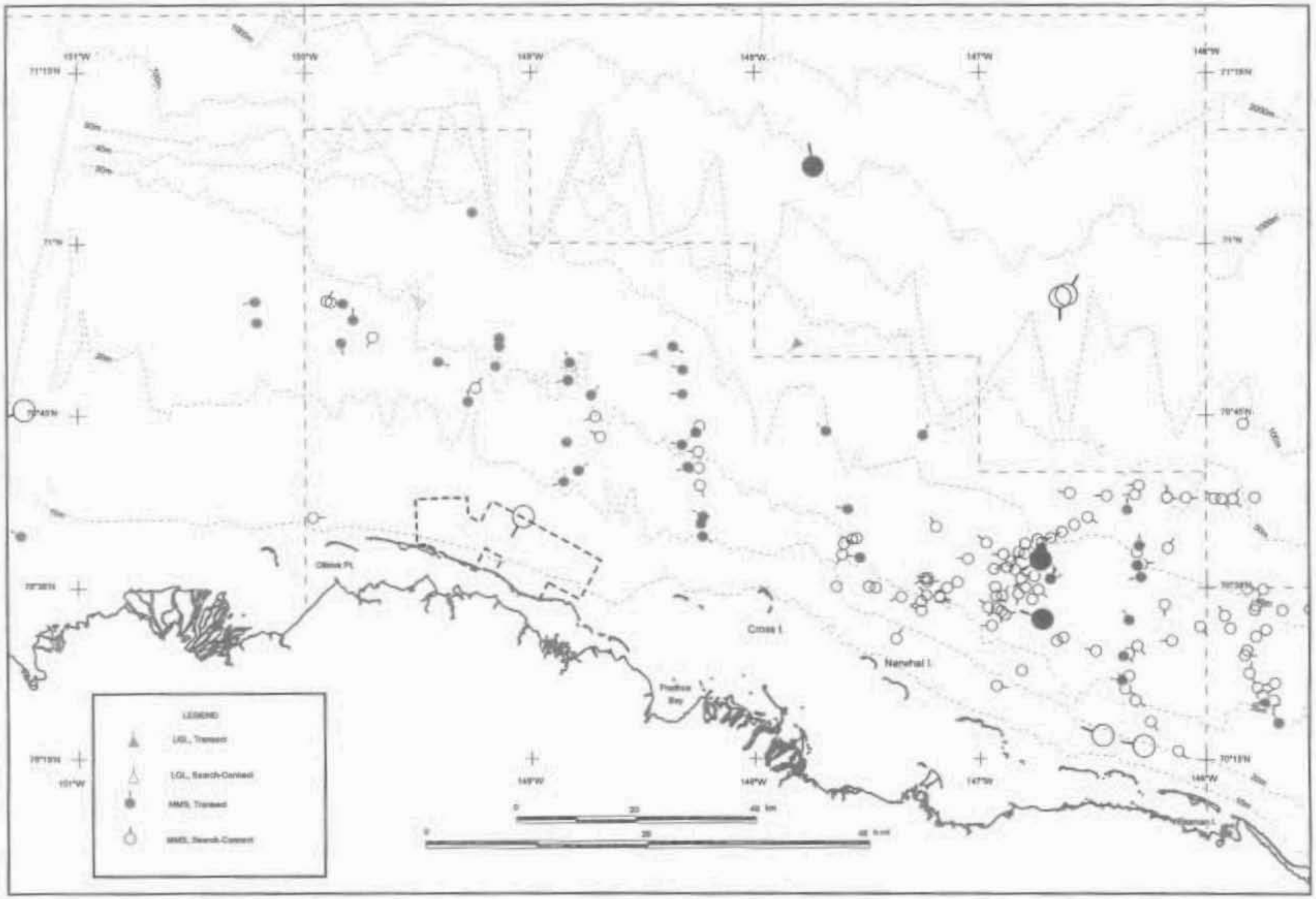

FIGURE 5.26. Bowhead whale sightings in the central Alaskan Beaufort Sea (146°-151°) during late summer and autumn of 1994-95 based on MMS and LGL aerial surveys. The few 1994 sightings are distinguished by large symbols. Seismic patches shot during 1-18 Sep. 1996 are outlined for cross-reference.

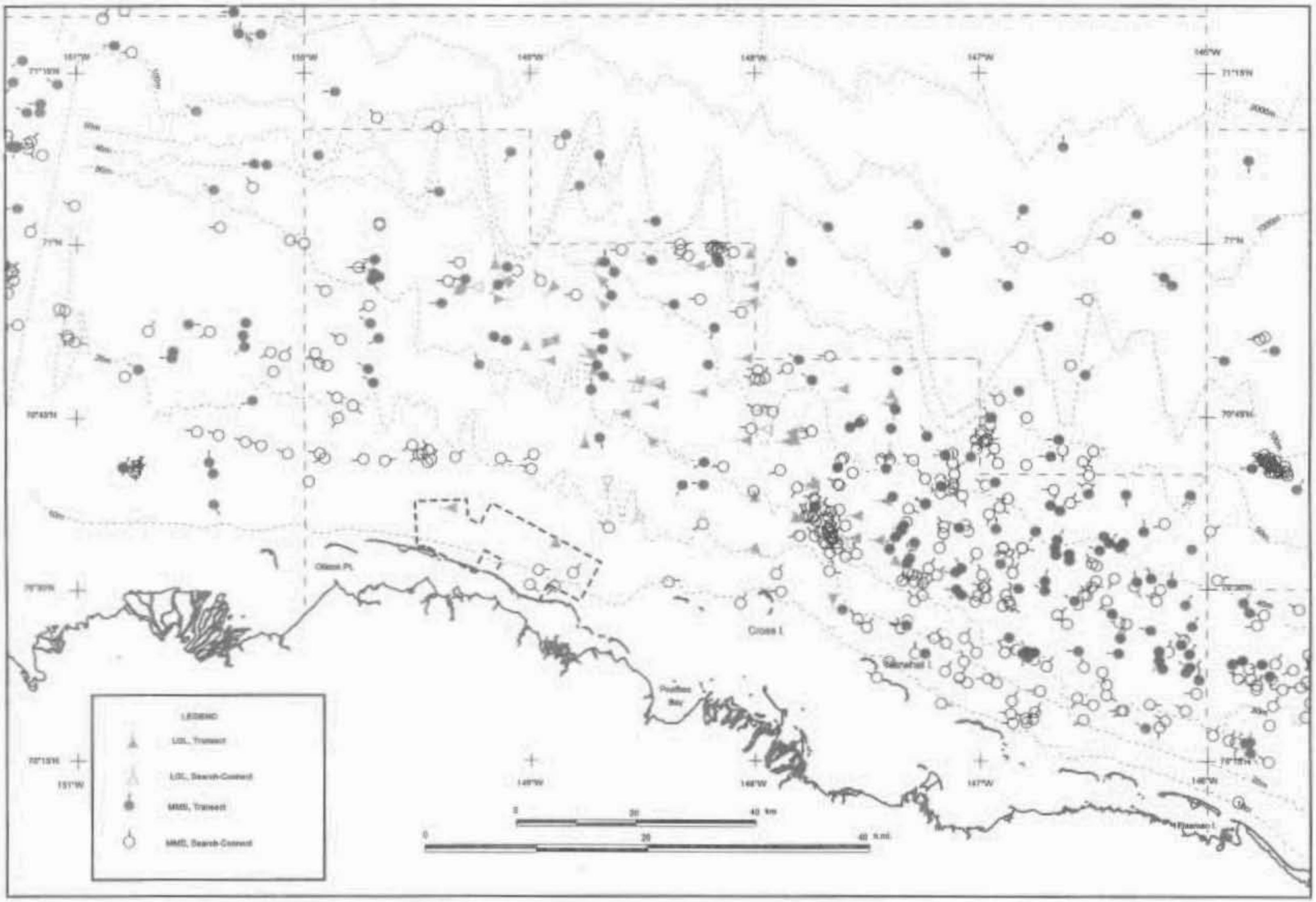

FIGURE 5.27. Bowhead whale sightings in the central Alaskan Beaufort Sea (146°-151°) during late summer and autumn of 1979-93 based on MMS and LGL aerial surveys. Seismic patches shot during 1-18 Sep. 1996 are outlined for cross-reference.

In previous related analyses for 1979-95 (e.g., LGL and Greeneridge 1996), we excluded bowhead sightings and survey effort during high sea states or periods of poor visibility, when the probability of detecting marine mammals is much reduced. This is a standard practice in analyses of aerial survey data, and results in more consistent and reliable data. In the 1979-95 period, this "correction" process excluded 8.8% (8396 of 94,940 km) of the "transect" survey effort and 7.7% (16 of 209) of the bowhead sightings.

In 1996, the "correction" process excluded 18.5% (2398 of 12,971 km) of the combined LGL and MMS survey effort within the 147°W-150°30'W area, and 23% (15 of 65) of the "Transect" sightings of bowheads in that area. We are reluctant to exclude such a large number of sightings from the 1996 dataset. Although the 1996 sighting data are substantial when compared to other individual years, the 1996 dataset—either with or without the "poor visibility" sightings—is small for the types of analyses we are conducting. In most cases, we have shown the results in two ways, both including and excluding the "poor sightability" survey coverage and sightings. As shown below, similar results were obtained with either approach.

The distance-from-shore data were originally graphed, analyzed, and statistically tested by 5-km distance-from-shore bands. However, when the small dataset was subdivided into so many narrow bands, the numbers of sightings in adjacent 5-km bands were often very irregular. Therefore, we have graphed the distance-from-shore data by 10-km bands, resulting in smoother curves that are easier to interpret and probably more reliable. The Kolmogorov-Smirnov (K-S) tests reported below are based on data summarized by 5-km bands, for the reason described in §5.2, "Methods". However, K-S tests of the data grouped by 10-km bands were also done. Although K-S tests based on 10-km and 5-km bands often gave slightly different "D" values, all but one comparison resulted in the same conclusion regarding the significance of observed differences in distance-from-shore distributions. The one exception was a minor difference in results for 1996 vs. 1994-95 (see below).

1996 Seismic vs. 1996 No Seismic.—If westbound bowheads were displaced offshore by the seismic operation, distances from shore would be expected to be greater at times with than at times without seismic. The numbers of bowheads seen during late summer/autumn 1996 are plotted as a function of distance from shore in Figure 5.28, including periods with poor sightability. Sightings during "no-seismic" and "seismic" conditions are distinguished. The "seismic" category includes full array seismic, partial array seismic, and post-seismic (0-3.5 h after termination of full array airgun operations).

All Bowheads: The modal distance-from-shore was farther offshore during "seismic" periods than during "no-seismic" periods, but the difference was not statistically significant. During periods that may have been influenced by seismic noise, the peak number of sightings was in the 20-30 km from shore band (Fig. 5.28A). During no-seismic periods, the peak number of sightings was in the 10-20 km from shore band with a slightly lower number in the 20-30 km band (16 and 13 sightings, respectively). During no-seismic periods, relatively high numbers of sightings also occurred in the 30-40 and 40-50 km bands. Thus, the distance-from-shore distribution was broader without seismic than with seismic. Sightings

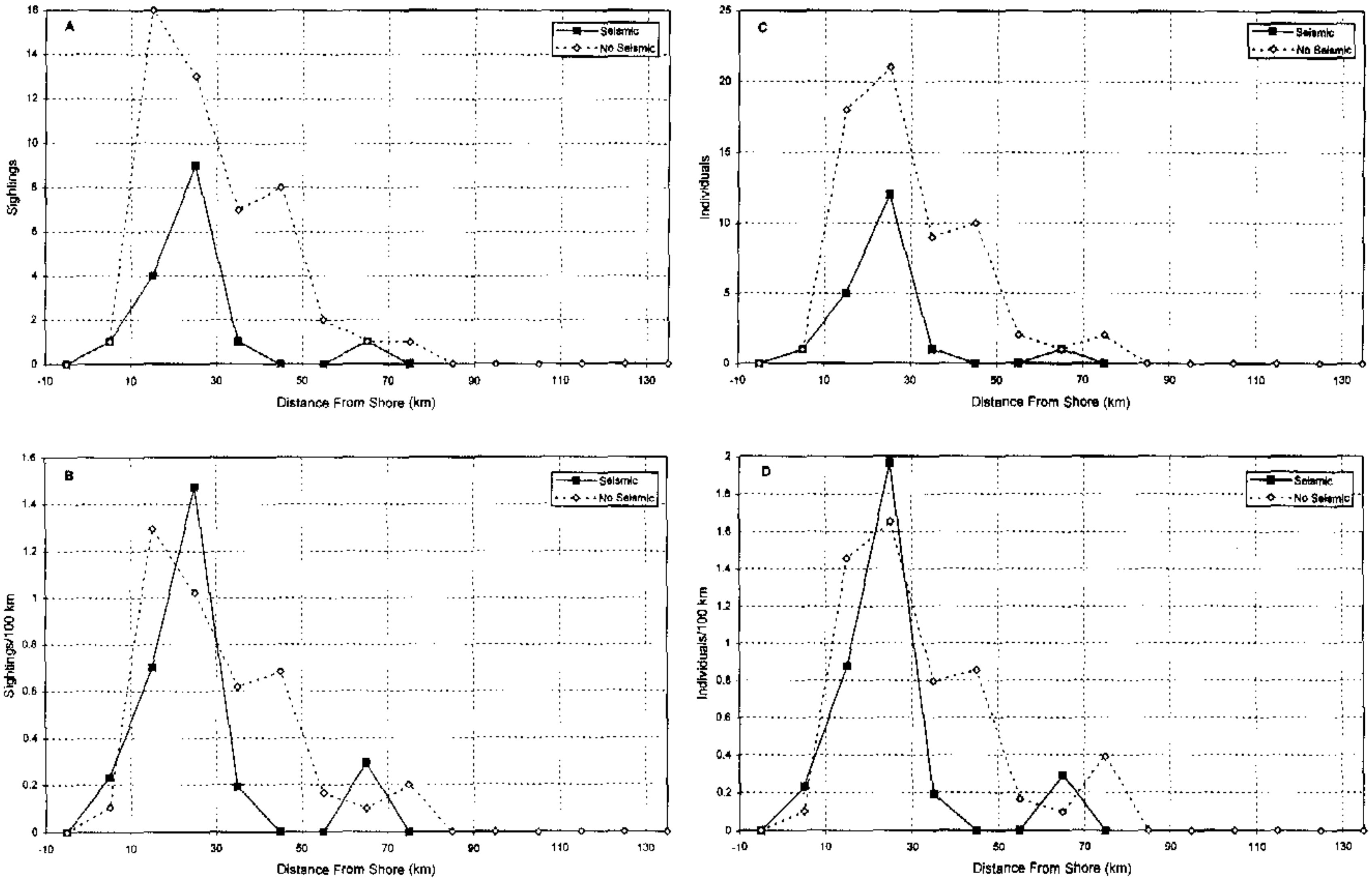

FIGURE 5.28. Distributions of bowheads vs. distance from shore during "all seismic" periods vs. periods with no seismic, late summer/autumn 1996, including periods of poor sightability. Based on LGL and MMS "Transect" aerial surveys in the Northstar region of the central Alaskan Beaufort Sea (147°-150°30'). ***(A)*** Sightings, ***(B)*** sightings per 100 km of surveys, ***(C)*** individuals, and ***(D)*** individuals per 100 km of surveys. See Fig. 5.29A for survey effort vs. distance from shore.

tended to extend both closer to shore and farther offshore in the absence of seismic, but the modal distance from shore was ~10 km farther offshore with seismic.

The difference in these two distributions was not statistically significant (Kolmogorov-Smirnov D=-0.284, two-tailed P>0.10).[4] The negative D value indicates that, in the distance from shore band with the largest observed difference in cumulative distribution, the cumulative no-seismic distribution was *farther* offshore than the cumulative "seismic" distribution. This resulted from the larger proportion of sightings 30-50 km offshore without seismic.

The same pattern persisted when we considered the number of individual bowheads seen per 100 km (Fig. 5.28C). The K-S test cannot be applied to the "individuals" data because individuals in a single group are not statistically independent.

All Bowheads per Unit Effort: In Fig. 5.28B,D the distance-from-shore data have been converted to sightings or individuals seen per 100 kilometers of aerial surveys. This was done using the data on survey effort by 5-km distance-from-shore band (Fig. 5.29A). When adjusted for the lesser amount of survey coverage during seismic periods, the sighting rates in the modal 10-km distance-from-shore categories were higher during seismic periods than no-seismic periods (1.5 vs. 1.3 sightings/100 km, respectively; Fig. 5.28B).

The modal distance-from-shore category during times potentially affected by seismic was 10 km farther offshore than that for bowheads sighted during periods with no seismic (20-30 km vs. 10-20 km, respectively). Despite this, the cumulative distribution of sightings/100 km was again centered *farther* offshore without seismic than with seismic, given the higher sighting rates 30-50 km offshore with no seismic than with seismic. The differences between the two distributions remained statistically non-significant (D=-0.282, two-tailed P>0.10).[5]

The individuals/100 km distributions with and without seismic were more similar than the sightings/100 km distributions (Fig. 5.28D vs. 5.28B). The 10-km band with the highest individuals/100 km figure was the 20-30 km band during both seismic and no-seismic periods.

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[4] For a Kolmogorov-Smirnov D of 0.284 to be significant with 2-sided $\alpha = 0.05$, sample sizes would have to increase by a factor of 1.9, i.e. from the present 49 sightings without seismic and 16 with seismic to 93 without and 30 with seismic. Alternatively, if sample sizes under the two conditions were equal, n = 46 + 46 would be sufficient for D=0.284 to be significant at α=0.05.

The 0.284 D_{max} value was in the opposite direction to that predicted (whales farther offshore without seismic). D_{max} for the predicted effect (whales farther offshore with seismic) was 0.121. A large increase in sample size, to about n = 200 + 200, would be needed before such a small D_{max} would become significant based on a 1-sided $\alpha = 0.05$.

[5] For D = 0.282 to be significant with 2-sided $\alpha = 0.05$, sample sizes would have to increase by a factor of 1.92, i.e. from 49 + 16 to 94 + 31, or to equal samples of 47 + 47. D_{max} for the predicted effect (whales farther offshore with seismic) was 0.100. A very large increase in sample size, to about n = 295 + 295, would be needed for such a small D_{max} to be significant based on 1-sided $\alpha = 0.05$.

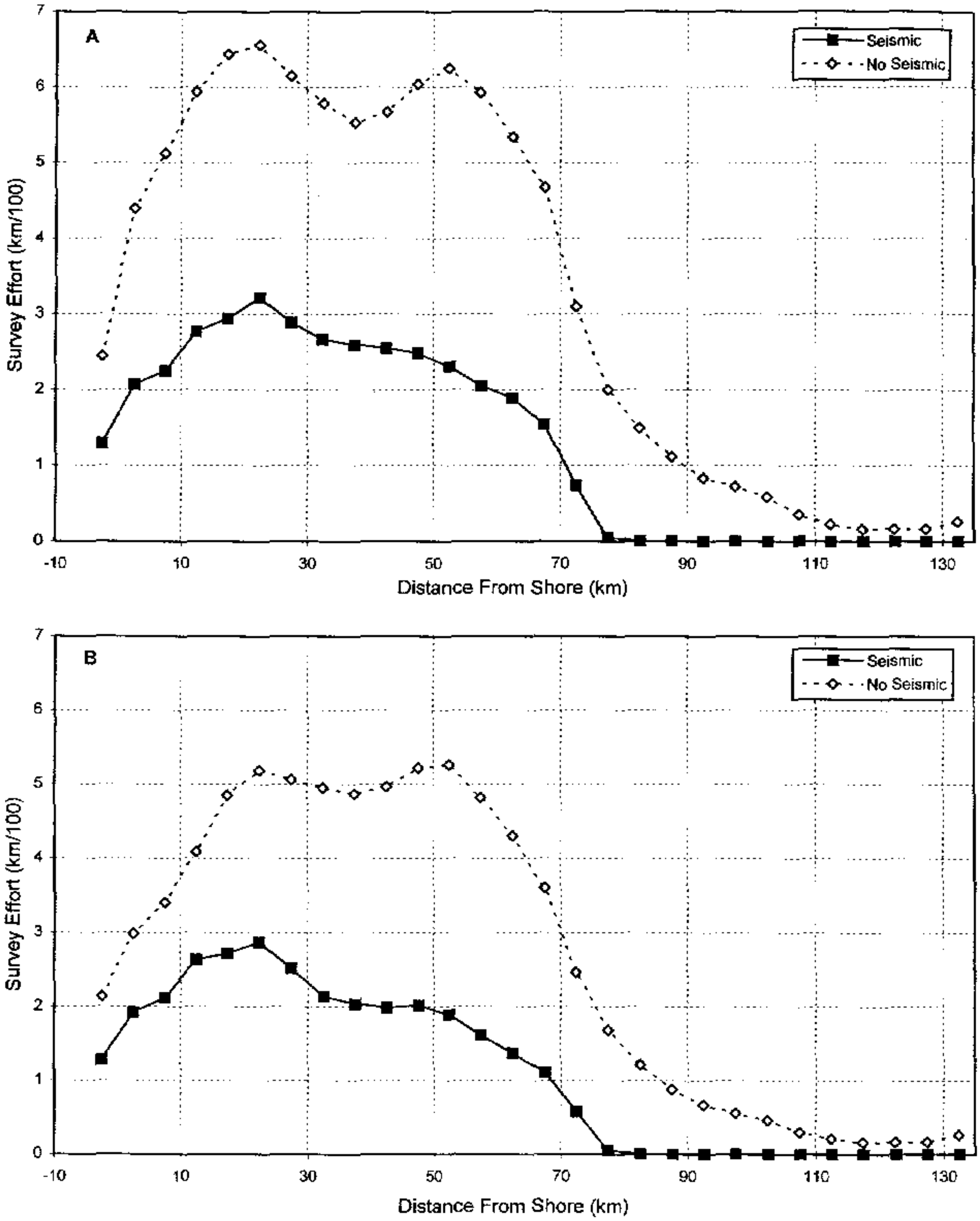

FIGURE 5.29. Aerial survey effort at various distances from shore during "all seismic" periods vs. periods with no seismic, late summer/autumn 1996; periods of poor sightability *(A)* included and *(B)* excluded. Based on LGL and MMS "Transect" aerial surveys in the Northstar region of the central Alaskan Beaufort Sea (147°-150°30').

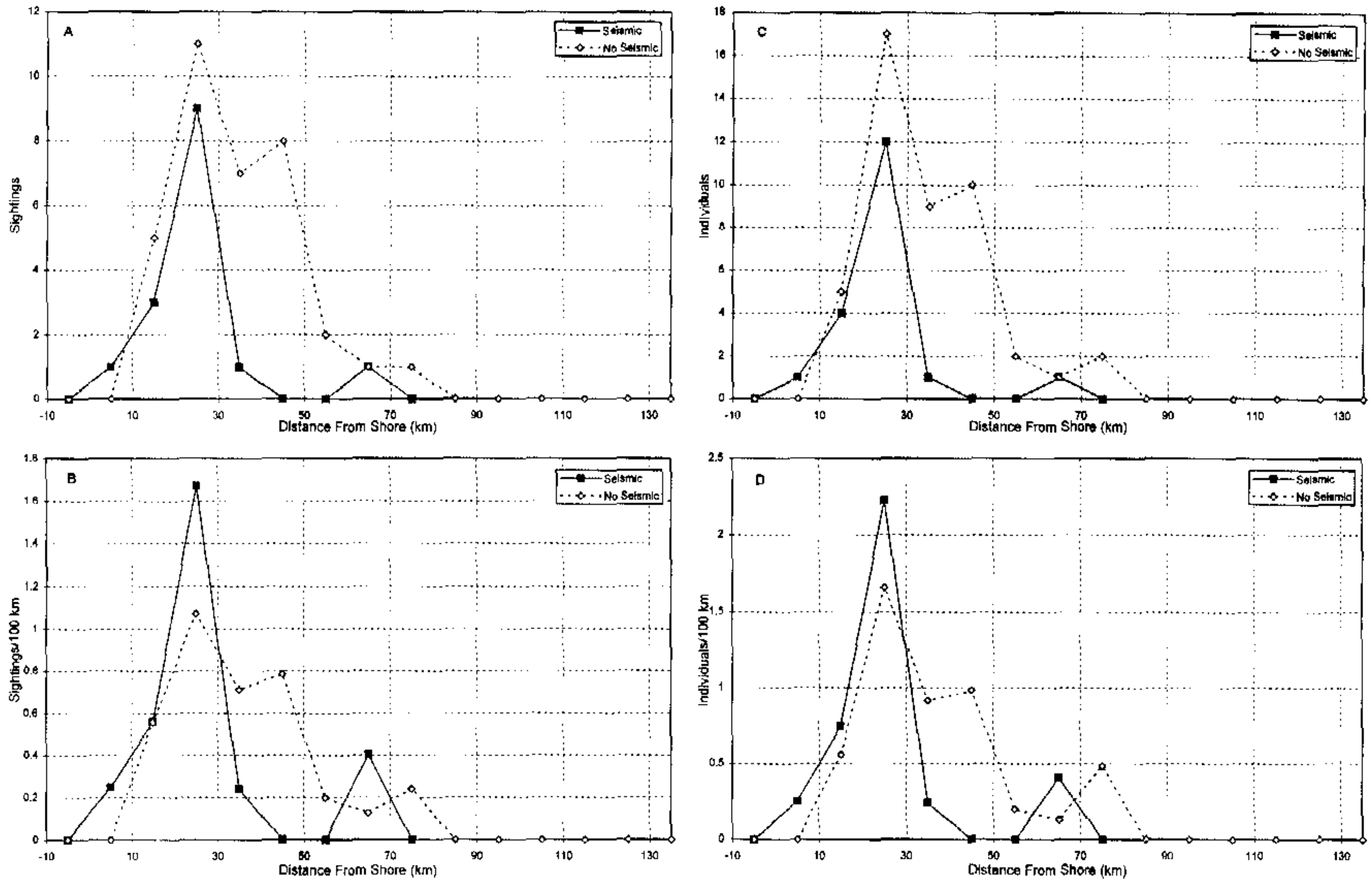

FIGURE 5.30. Distributions of bowheads vs. distance from shore during "all seismic" periods vs. periods with no seismic, late summer/autumn 1996, excluding periods of poor sightability. See Fig. 5.29B for survey effort vs. distance from shore. Otherwise as in Fig. 5.28.

Poor Sightability Data Excluded: Figure 5.30 shows the corresponding results excluding sightings and effort under poor visibility and high sea state (mainly on 5 Sep 1996; see Table 5.3). Figure 5.29B shows the associated survey effort. Excluding sightings under poor survey conditions, the modal distance from shore is in the 20-30 km band under both "seismic" and "no-seismic" conditions. Sightings tended to extend farther from shore under no-seismic than seismic conditions (Fig. 5.30). For sightings, this difference between seismic and no-seismic conditions was marginally significant (D=-0.419, 0.1>P>0.05, two-tailed). However, sightings/ 100 km during seismic vs. no-seismic periods were similar (D=-0.376, two-tailed P>0.10).

The sighting distributions plotted in Fig. 5.28A-D, including poor sightability data, are based on only 16 "seismic" and 49 "no-seismic" sightings during the BPXA/LGL and MMS surveys combined. The distributions plotted in 5.30A-D, excluding the poor sightability data, are based on only 15 "seismic" and 35 "no-seismic" sightings.

This dataset is too small to justify firm conclusions about the occurrence or extent of displacement of the migration corridor when bowhead whales are migrating past a seismic operation in nearshore waters. The tendency for the highest proportion of the bowhead sightings to occur 20-30 km from shore with seismic vs. 10-20 km from shore during no-seismic periods (Fig. 5.28) is consistent with the possibility of seaward displacement of sightings during seismic. This tendency was not evident when data from poor sightability conditions were omitted (Fig. 5.30). Also, one test suggested a marginally significant tendency for sightings to occur *farther* offshore during no-seismic periods than during seismic periods. In any case, the main migration corridor during periods potentially influenced by seismic (including periods 0-3.5 h after seismic ended) was apparently within 20-30 km from shore, and thus within ~10-20 km from the northern edge of the area of seismic exploration (Fig. 5.30).

1996 East vs. 1996 West.—Another approach to examining whether seismic exploration affected bowhead distribution in the Northstar area in 1996 is to compare the distance-from-shore distributions of bowheads in eastern and western portions of the study area. The distributions of bowheads east of 148°10'W (most of which would be approaching Northstar) and west of 148°10'W (passing or past Northstar) are compared in Figure 5.31, using all data, including those from periods with poor sighting conditions. The 20 sightings in the eastern portion of the study area tended to be farther from shore than the 40 sightings in the western portion of study area, contrary to the possible expectation that seismic exploration near Northstar might push bowheads farther offshore. Peak numbers of sightings in the eastern and western portions of the study area occurred in the 20-30 and 10-20 km bands, respectively (Fig. 5.31A). However, the sighting distributions in the two regions were not significantly different (K-S test, D=-0.325, two-tailed P>0.10). For individual bowheads, the 20-30 km from shore band was the modal band in both the eastern and western areas, but again with some tendency for more individuals to be seen close to shore in the west (Fig. 5.31B).

When corrected for survey effort (Fig. 5.32A) the sightings/100 km data again indicated a tendency for bowhead sightings to be farther offshore in the east than in the west. However, the difference was not statistically significant (D=-0.232, two-tailed P>0.10).

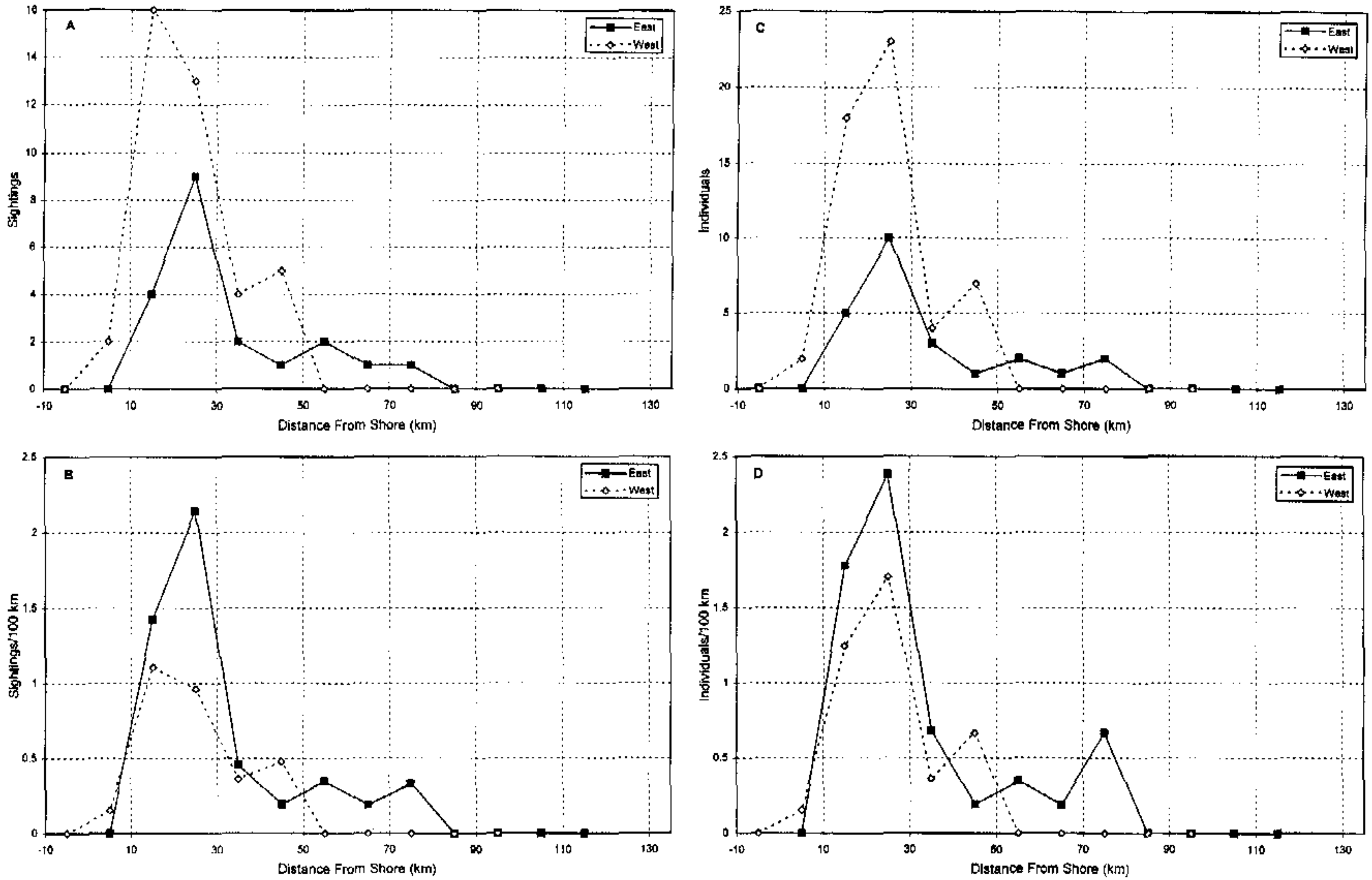

FIGURE 5.31. Distributions of bowheads vs. distance from shore in areas east and west of 148°10'W, late summer/autumn 1996, including periods of poor sightability. See Fig. 5.32A for survey effort vs. distance from shore. Otherwise as in Fig. 5.28.

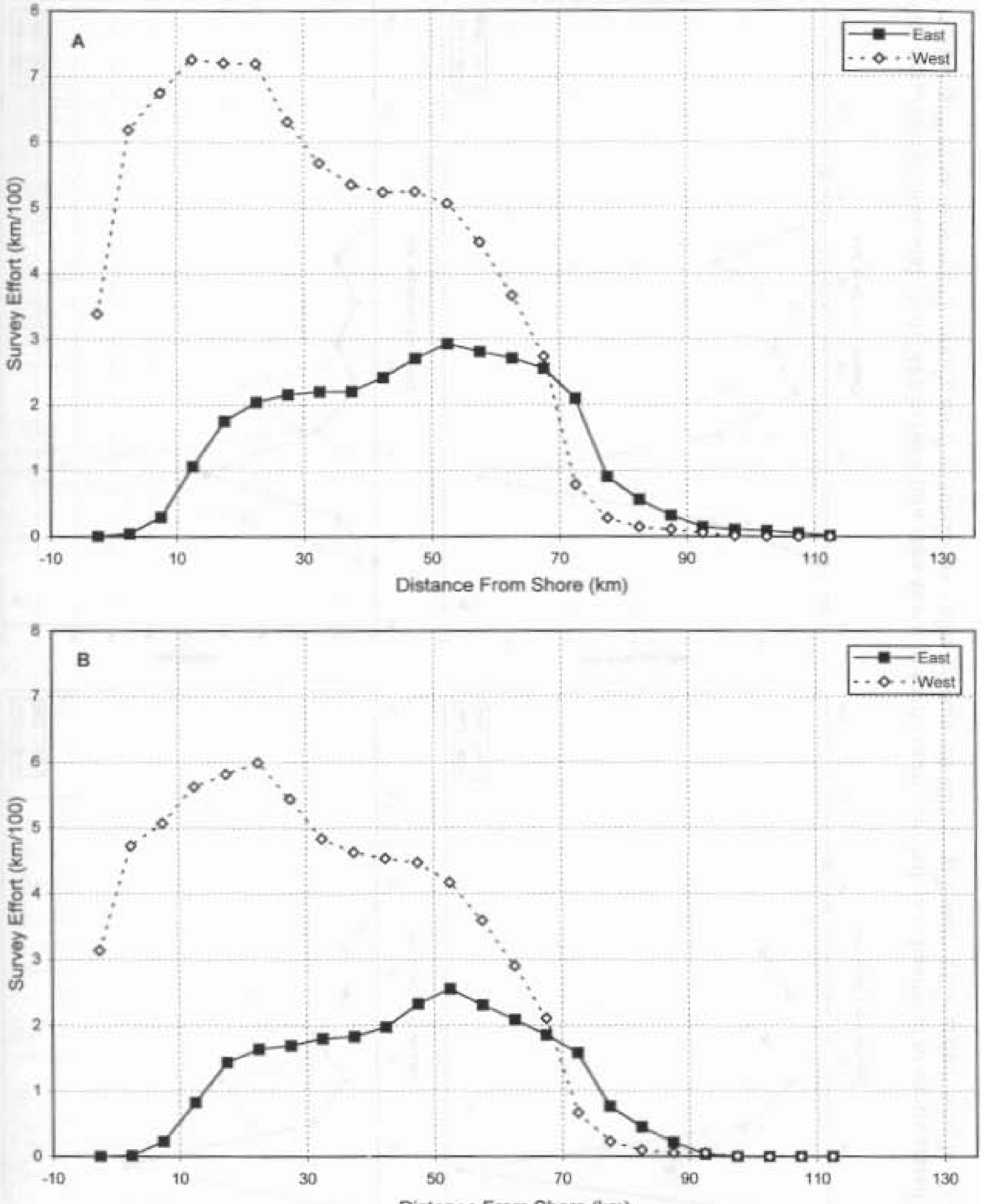

FIGURE 5.32. Aerial survey effort at various distances from shore in areas east and west of 148°10'W, late summer/autumn 1996; periods of poor sightability *(A)* included and *(B)* excluded. Based on LGL and MMS "Transect" aerial surveys in the Northstar region of the central Alaskan Beaufort Sea (147°-150°30').

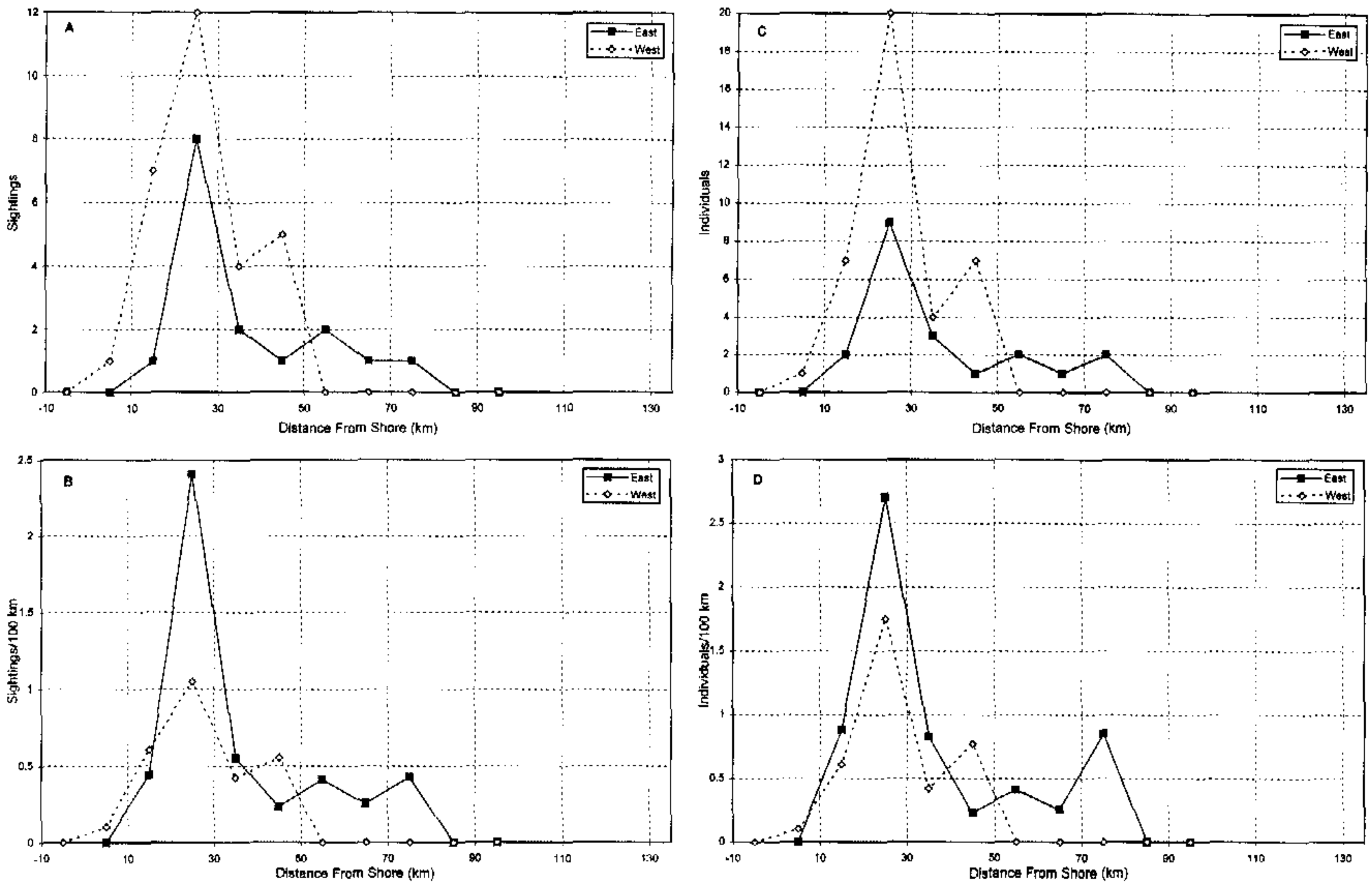

FIGURE 5.33. Distributions of bowheads vs. distance from shore in areas east and west of 148°10'W, late summer/autumn 1996, excluding periods of poor sightability. See Fig. 5.32B for survey effort vs. distance from shore. Otherwise as in Fig. 5.28.

The same E-W comparisons were conducted with the smaller dataset excluding sightings under poor visibility/high sea state conditions. This reduced dataset included 16 sightings in the east and 29 in the west (Fig. 5.33). Figure 5.32B shows the associated survey coverage. In both areas, the modal distance from shore was 20-30 km for sightings, individuals, sightings/100 km, and individuals/100 km (Fig. 5.33A-D). Sightings and individuals again tended to extend farther offshore in the eastern than in the western area. However, this tendency was not statistically significant for either sightings or sightings/100 km (D= -0.302 and -0.227, respectively; two-tailed P>0.10 in each case).

Whether or not bowheads really tend to be farther offshore in the eastern than in the western area, there certainly was no tendency for sightings to be farther offshore in the western area near and just west of Northstar.

The above east-west comparisons include all 1996 sightings, whether or not seismic operations were underway at the time of each sighting. Logically, we should also compare the distances from shore in the eastern and western areas at times with seismic. There were nine bowhead sightings during seismic plus eight sightings <3.5 h after seismic ended. Of these 17 sightings, 13 were in the west and only four in the east (Fig. 5.23). The sample sizes, especially in the east, were too low for meaningful comparison.

1996 vs. 1994-95.—If westbound bowheads were displaced offshore by the seismic operation, distances from shore would be expected to be greater in 1996 than in years with similar ice cover but little offshore industrial activity, e.g. 1994-95. Figure 5.34 compares the data from 1996 vs. 1994-95, including sightings and survey effort during periods with poor sightability. There were 65 "Transect" sightings in 1996 and 44 in 1994-95 (mainly from 1995).

As noted in §5.2, 1996 was classed as a light ice year by the Naval Ice Center. In the Northstar area, 1996 perhaps should be considered a moderate ice year. Given this, and the need for as large a "baseline" sample as possible, we considered adding the data from any prior years with moderate ice but little industrial activity to the 1994-95 baseline dataset. However, there were no years with moderate ice but little industrial activity during the 1979-93 period for which aerial survey data are available.

Bowheads tended to be seen closer to shore in 1996 than in 1994-95 (Fig. 5.34). Peak numbers of sightings and of individuals were in the 20-30 km from shore band in both 1996 and 1994-95. However, in 1996 (unlike 1994-95) there were almost as many sightings and individuals in the 10-20 km band (Fig. 5.34A,C). The distribution of sightings was significantly closer to shore in 1996 than in 1994-95 (K-S test, D=-0.293, two-tailed P<0.05). The associated survey effort is shown in Figure 5.35A. When reanalyzed based on sightings per unit effort (Fig 5.34B), bowhead distribution was again found to be concentrated significantly closer to shore in 1996 than in 1994-95 (D=-0.284, two-tailed P<0.05).

Within the smaller dataset that excluded the "poor sightability" data, there were 50 sightings in 1996 and 43 in 1994-95. With these data, the bowhead distribution again tended to be slightly closer to shore during 1996 than during 1994-95, but the tendency was weak

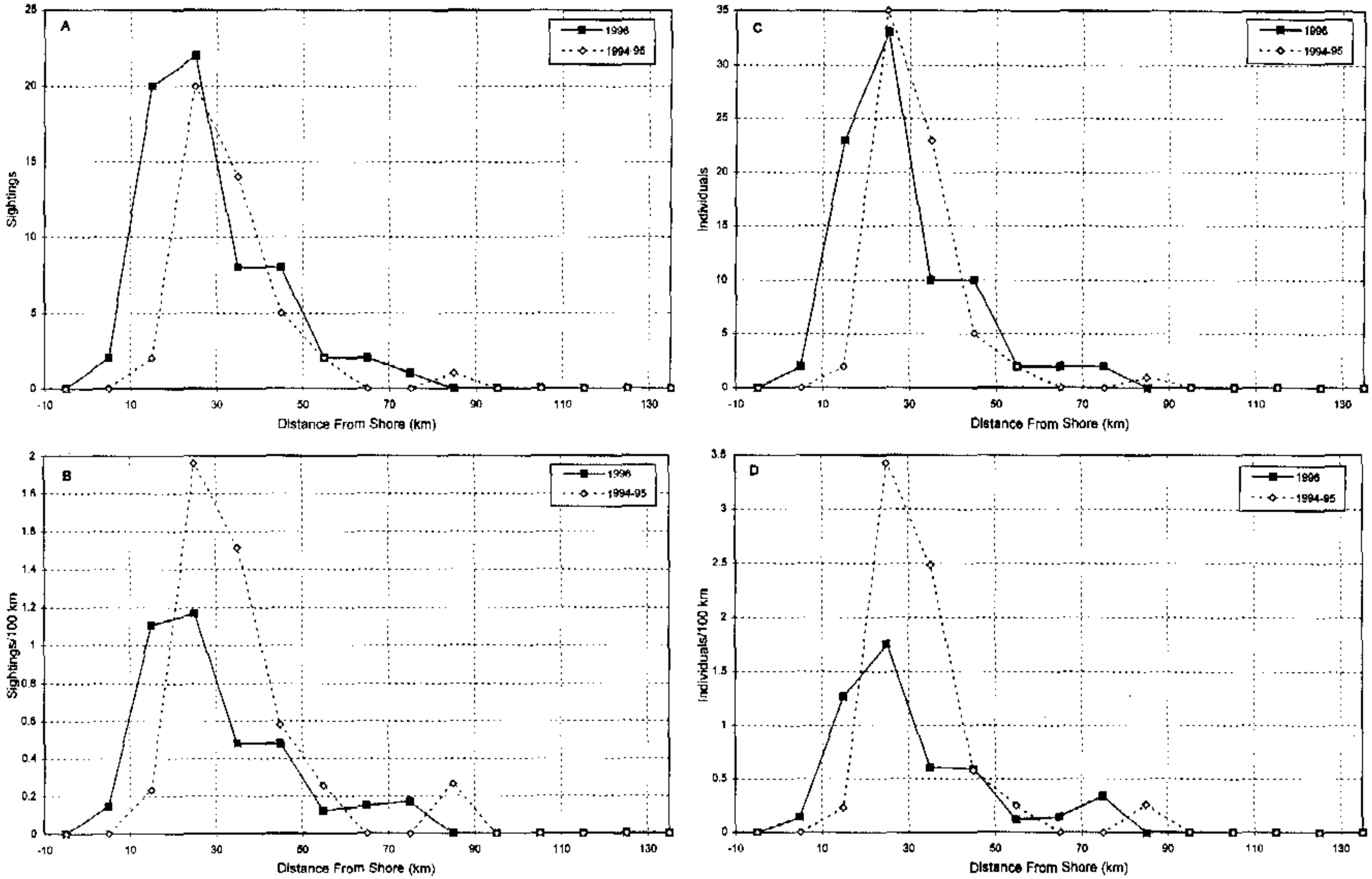

FIGURE 5.34. Distributions of bowheads vs. distance from shore during late summer/autumn of 1996 vs. 1994-95 (light ice years with nil/little industrial activity), including periods of poor sightability. See Fig. 5.35A for survey effort vs. distance from shore. Otherwise as in Fig. 5.28.

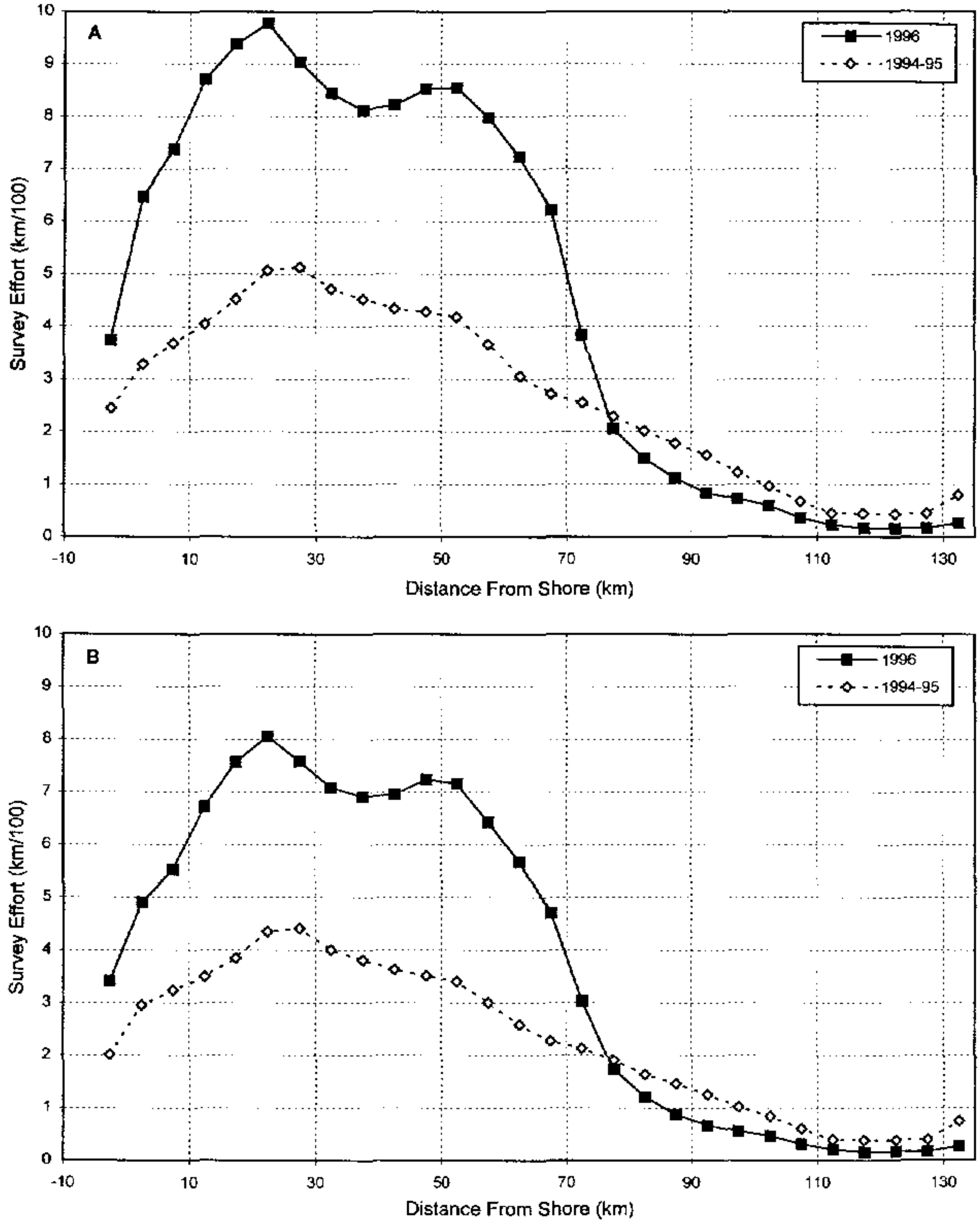

FIGURE 5.35. Aerial survey effort at various distances from shore during late summer/autumn of 1996 vs. 1994-95 (light ice years with nil/little industrial activity); periods of poor sightability *(A)* included and *(B)* excluded. Based on LGL and MMS "Transect" aerial surveys in the Northstar region of the central Alaskan Beaufort Sea (147°-150°30').

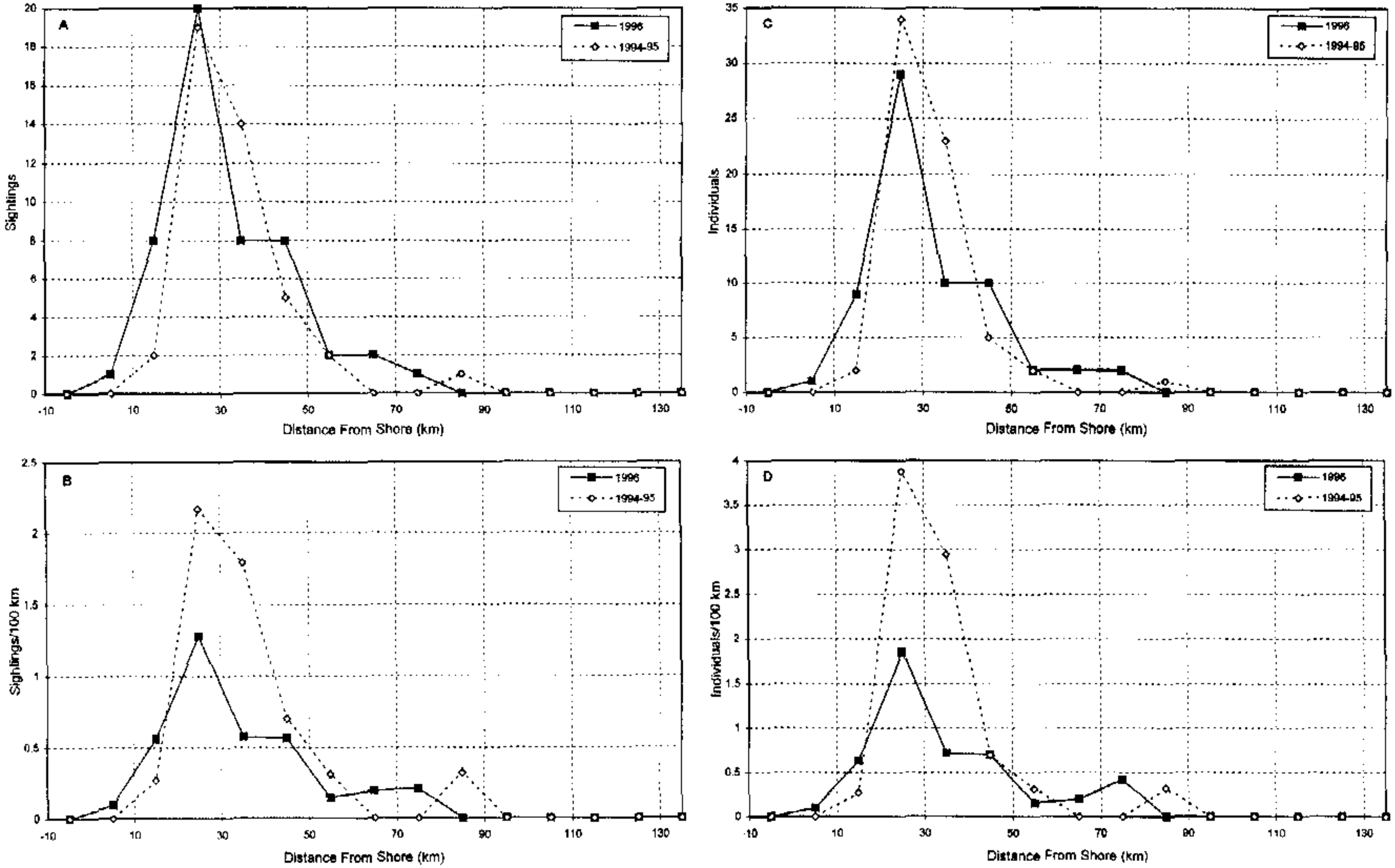

FIGURE 5.36. Distributions of bowheads vs. distance from shore during late summer/autumn of 1996 vs. 1994-95 (light ice years with nil/little industrial activity), excluding periods of poor sightability. See Fig. 5.35B for survey effort vs. distance from shore. Otherwise as in Fig. 5.28.

and less conspicuous than in the larger dataset (Fig. 5.36 vs. 5.34). The difference was not statistically significant when based either on sightings (D=-0.133, two-tailed P>0.10) or on sightings per 100 km of survey effort (D=-0.137, two-tailed P>0.10).

Thus, comparison of 1996 sighting data with data from two years having similar ice conditions but little industrial activity revealed no evidence that bowheads were distributed farther from shore in 1996. In fact, the bowhead migration corridor tended to be closer to shore in 1996 than in 1994-95.

The above analyses include all 1996 sightings, whether or not seismic operations were underway at the time of each sighting. It is also relevant to compare distances from shore for bowheads seen during "seismic" periods of 1996 ("seismic" curves in Fig. 5.28-5.30) vs. those for all bowheads seen in 1994-95, the "quiet" light-ice years (Fig. 5.34-5.36).

The modal distance-from-shore category was 20-30 km offshore both during the 1996 seismic periods and during 1994-95 as a whole. However, proportionally more bowheads were found <20 km offshore and proportionally fewer were found >30 km offshore during the 1996 seismic periods than during 1994-95. This was true whether or not "poor sightability" data were excluded, and for all methods of analysis (sightings, individuals, sightings/100 km, or indiv./100 km). The difference between 1996 seismic data and 1994-95 data was statistically significant when all data were included and compared by 5-km intervals (D=-0.415 for sightings and D=-0.402 for sightings/100 km; n=16 and 44 and two-tailed P<0.05 in each case).[6] The difference was marginal or non-significant when "poor sightability" data were excluded (D=-0.388 for sightings, 0.1>P>0.05, and D=-0.361 for sightings/100 km, P>0.1; n=15 and 43 in each case).

Thus, there was no indication that the migration corridor was farther from shore with seismic in 1996 than during the "quiet" seasons of 1994-95. If anything, the migration corridor tended to be farther offshore without seismic in 1994-95. However, this result should be interpreted cautiously given the small number of "seismic" sightings in 1996, and the fact that some of these whales were seen 0-3.5 h after seismic ended.

Years With Little vs. Substantial Industrial Activity.—If westbound bowheads were displaced offshore by industrial activities in general, including both seismic and drilling activities, distances from shore would be expected to be greater in years with substantial industrial activity. Distance-from-shore data for bowheads seen in the Northstar area are plotted for light ice years with nil or little vs. substantial offshore industrial activity in Figure 5.37. This Figure excludes data from periods with poor sightability. Years with substantial industrial activity included years with substantial seismic exploration, offshore drilling, or both in the central Alaskan Beaufort Sea, including the western Camden Bay area. There

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[6] Both differences were only marginally significant (0.1>P>0.05) when the analysis was done based on 10-km intervals. These were the only K-S tests reported in this Chapter in which use of 5- vs. 10-km intervals resulted in different significance levels.

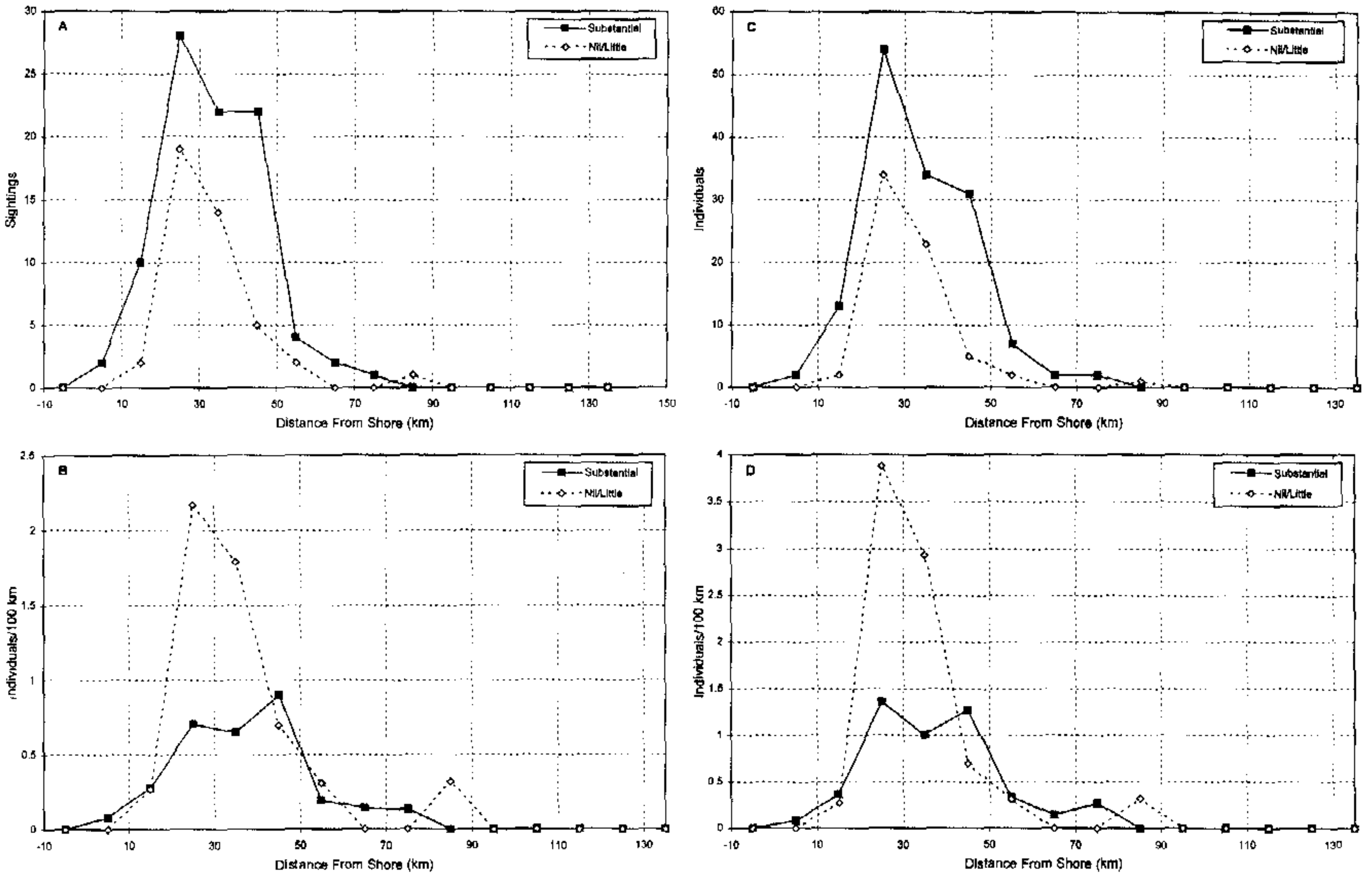


FIGURE 5.37. Distributions of bowheads vs. distance from shore during late summer/autumn of light ice years with substantial industrial activity vs. nil/little industrial activity, excluding periods of poor sightability. See Fig. 5.38 for survey effort vs. distance from shore. Otherwise as in Fig. 5.28.

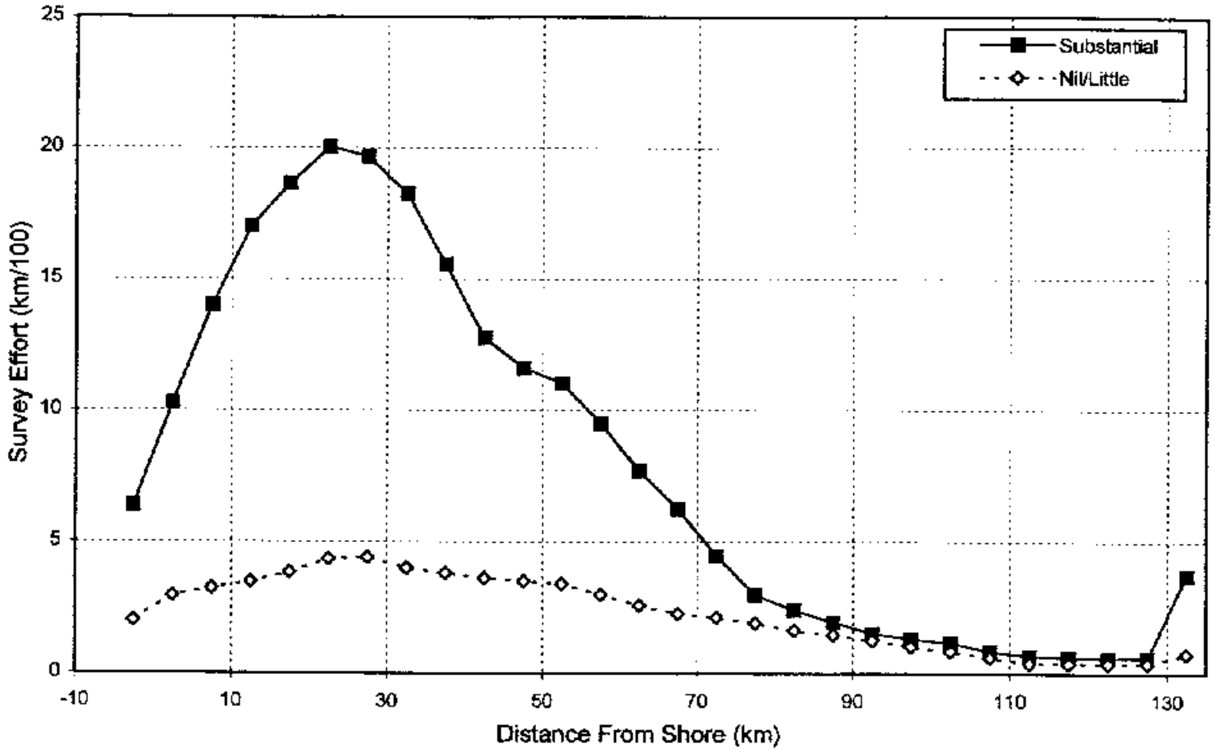


FIGURE 5.38. Aerial survey effort at various distances from shore during late summer/autumn of light ice years with substantial vs. nil/little industrial activity; periods of poor sightability excluded. Based on LGL and MMS "Transect" aerial surveys in the Northstar region of the central Alaskan Beaufort Sea (147°-150°30').

were 43 bowhead sightings in the two light-ice years with little or no industrial activity (1994-95) and 91 sightings in the five light-ice years classed as having substantial industrial activity (1982, 1987, 1989, 1990 and 1996).

Peak numbers of sightings and of individuals in the Northstar region were in the 20-30 km distance-from-shore zone in both groups of years (Fig. 5.37A, C). The overall distribution of sightings tended to extend somewhat farther offshore during "industrial" years than in years without much industrial activity. However, the difference was not statistically significant (K-S D=0.196, two-tailed P>0.10).

When the sightings were corrected for the onshore-offshore distribution of survey effort (*cf.* Fig. 5.38), the main migration corridor again seemed to extend farther from shore during years with industrial activity (Fig. 5.37B). High sighting rates (/100 km) occurred in the 20-

40 km distance-from-shore zone in years with little industrial activity, and in the 20-50 km zone during "industrial" years. The modal categories were 20-30 km vs. 40-50 km. This difference was statistically significant (D=0.253, n = 91, 43; two-tailed 0.05>P>0.01).

Overall, bowhead sightings tended to be slightly farther offshore during five light ice years with substantial industrial activity than during two light ice years without much activity. This difference was statistically significant when allowance was made for survey effort at each distance from shore.

Summary of Distances from Shore.—The number of bowhead sightings within the Northstar region (147°-150°30'W) during LGL and MMS aerial surveys in 1996 was small, and only a minority of these sightings were during (n=9) or within 3.5 h after (n=8) periods of seismic exploration. For this and other reasons, it is not appropriate to draw general conclusions about effects of seismic exploration on the position of the bowhead migration corridor based on this 1996 monitoring study alone. However, the following points were evident from the data available:

1996 Seismic vs. 1996 No Seismic

If westbound bowheads were displaced offshore by the seismic operation, distances from shore would be expected to be greater at times with than at times without seismic. Bowheads tended to be seen both closer to shore and farther offshore without seismic. *The modal distance from shore was ~10 km farther offshore with seismic, consistent with the possibility of seaward displacement by seismic*, when data collected under poor sightability conditions were included. However, the distributions with and without seismic overlapped broadly, and when poor sightability data were excluded sightings tended to be *closer* to shore with seismic than without seismic. The main migration corridor during periods potentially influenced by seismic was apparently 20-30 km from shore, or ~10-20 km from the northern edge of the area of seismic exploration.

1996 East vs. 1996 West

If westbound bowheads were displaced offshore by the seismic operation, distances from shore would be expected to be greater in the western than in the eastern part of the Northstar region. No evidence of this was found when we considered 1996 as a whole (periods with and without seismic combined).

We wanted to compare distances from shore in the east and west considering only the times with seismic. However, the number of sightings with seismic was too small, especially in the east.

1996 vs. 1994-95

If westbound bowheads were displaced offshore by the seismic operation, distances from shore would be expected to be greater in 1996 than in years with similar ice cover but little offshore industrial activity, e.g. 1994-95. We found no evidence that bowheads were distributed farther from shore in 1996 (either overall or during times with seismic) than in 1994-95. If anything, bowhead migration tended to be closer to shore during 1996, the year with seismic.

Years with Little vs. Substantial Industrial Activity

If westbound bowheads were displaced offshore by industrial activities in general, including both seismic and drilling activities, distances from shore would be expected to be greater in years with substantial industrial activity in the Northstar area and/or western Camden Bay. *Consistent with this hypothesis, bowhead sightings tended to be slightly farther offshore during five light ice years with substantial industrial activity than during two light ice years without activity.* This difference was statistically significant ($P<0.05$).

Available data are insufficient to determine whether the tendency for the southern edge of the main bowhead migration corridor to be farther offshore with seismic or other industrial activities is indicative of a causal relationship. The tendency was not statistically significant for seismic. However, considering the larger sample of data from five light-ice years having substantial amounts of offshore industrial activity (seismic and/or drilling), bowheads were distributed significantly farther offshore during those years than in two light ice years without much industrial activity.

The observed tendencies, although statistically weak, are qualitatively consistent with the experience of bowhead hunters, who have reported that seismic exploration and other industrial activities displace the migration corridor of bowhead whales (e.g., Jolles [ed.] 1995; Rexford 1996; Kanayurak et al. 1997). However, there was much overlap between the migration corridors in years with vs. without seismic or other industrial activities. Also, most bowheads seen during periods with seismic exploration were within ~20-30 km from shore, and thus apparently passed within ~10-20 km of the northern edge of the seismic area. (The closest direct sightings during or immediately after periods of airgun array operations were 22-27 km from the airguns—see p. 5-45.) Data from additional years with seismic exploration will be required to confirm statistically that nearshore seismic exploration has measurable effects on the autumn migration corridor of bowheads and to estimate the magnitude of any effects.

5.3.4 Behavior and Headings

Previous sections have mapped the bowhead sightings during seismic periods (Fig. 5.23) and plotted their distances from shore (Fig. 5.30-5.32). In Figure 5.39 bowhead sightings with seismic are plotted in relation to the source vessel's position at the time of the sighting or, in the case of post-seismic sightings, at the time the source vessel stopped shooting seismic. The 17 sightings in Figure 5.39 ranged from 20.8 to 73.5 km from the source (Table 5.3). All but two of the sightings occurred within a ESE-WNW band paralleling the coastline north of the source. If the whales were traveling along the band from ESE to WNW, most would pass the source at distances of about 20-30 km north of the source. Two sightings were notably farther offshore in areas well to the NE and NW of the source.

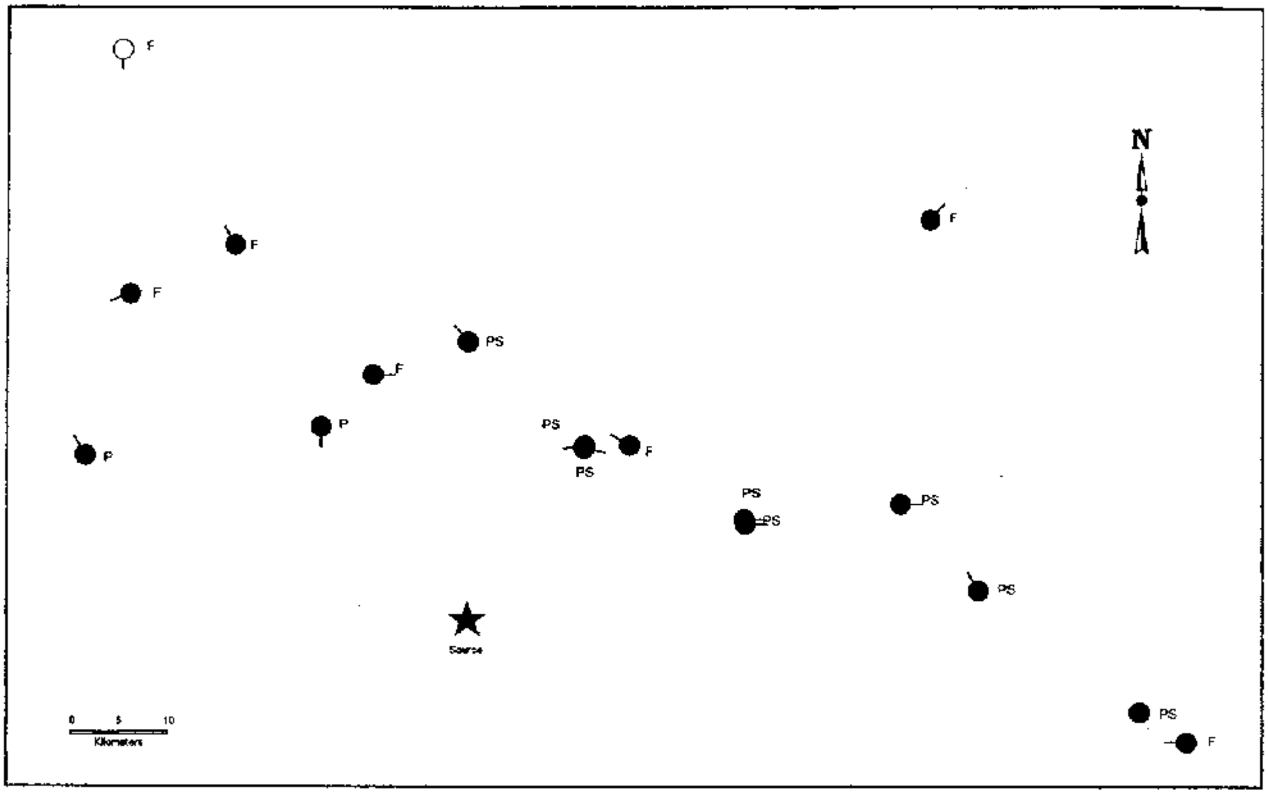


FIGURE 5.39. Bowheads sighted during "all seismic" periods plotted in relation to the location of the source vessel (star). F = full array, P = partial array, and PS = ≤3.5 h after end of a lengthy full array period. For PS cases, whale positions are plotted in relation to the position of the source vessel at the time when seismic operations ended. The single open symbol denotes an incidental sighting; solid symbols show "Transect" sightings. Based on LGL aerial surveys in the Northstar region of the central Alaskan Beaufort Sea, including periods of poor sightability. (There were no MMS sightings during F, P or PS periods.)

Eleven bowhead sightings were during active seismic periods (full and partial array) or within 12 minutes of the the end of a full-array seismic period. We include two sightings 11.4 min after seismic ended because these whales could not have traveled far within this short interval. These 11 sightings also occurred within 20.8 - 73.5 km of the source. Many of these sightings were well to the east or west of the source vessel. Thus, it is not known how closely some of these more distant bowheads may have approached the source during migration. However, the 11 "active seismic" sightings included five bowheads that were seen within about 21-27 km of the source.

Behavior.—The behaviors recorded for bowheads sighted during seismic periods included swimming and resting. Whales resting at the surface during active seismic work would not be exposed to such strong seismic pulses as would whales that dove. Thus, it is of interest to assess whether the proportion of whales resting at the surface was higher during seismic periods. Excluding the single search-connect sighting (a resting whale), there were 5 sightings of resting bowheads (31%) and 11 sightings of swimming bowheads (69%) during "all seismic" periods. Considering only the 9 sightings with full- or partial-array seismic at the actual time of the sighting (i.e. excluding "post seismic" cases), there were 4 sightings of resting bowheads (44%) and five sightings of swimming bowheads (56%). By comparison, behaviors were recorded for 48 of 49 "Transect" sightings without seismic (sightings during poor sightability included). Of these, 15 (31%) were resting, 25 (52%) were swimming, and 8 (16%) were involved in other behaviors (diving, milling, breaching).

Thus, the percentages of the bowhead sightings recorded as resting were identical during "all seismic" and "no-seismic" periods (31% of 16; 31% of 48) and slightly higher during active seismic (44% of 9). The percentages recorded as swimming were similar with "all seismic", "active seismic", and "no seismic" (69%, 56% and 52%, respectively). Overall, there was no indication that resting at the surface was appreciably more common during seismic than no-seismic periods, but the small sample sizes prevent firm conclusions.

Of the 11 sightings of swimming whales during "all seismic" periods, 6 (55%) were traveling at slow speed and 5 (45%) at medium speed. Within the comparable non-seismic sample, 13 of 25 sightings (52%) were recorded as swimming at slow speed and 12 (48%) at medium speed. These percentages were very similar (χ^2=0.05, df=1, P>0.75).

Headings During 1996.—During 1996 "Transect" surveys conducted by LGL and MMS within the Northstar region (147°-150°30'W), headings were recorded for 58 sightings of bowhead groups or single individuals. Of these, 35 (60%) were sightings of bowheads whose behavior was recorded as swimming, as opposed to resting, milling or some other activity.

The headings of the 35 "swimming" bowheads or groups (Fig. 5.40A) were bimodal. They included 23 headings (66%) concentrated around westward and northwestward directions (221-330°T, a 110° range) and 12 headings (34%) in other directions, primarily eastward. The vector mean heading was 313°T with an angular deviation of 66°, based on the method of Batschelet (1981). However, with a strongly bimodal distribution of this nature, the vector mean and angular deviation must be interpreted with caution.

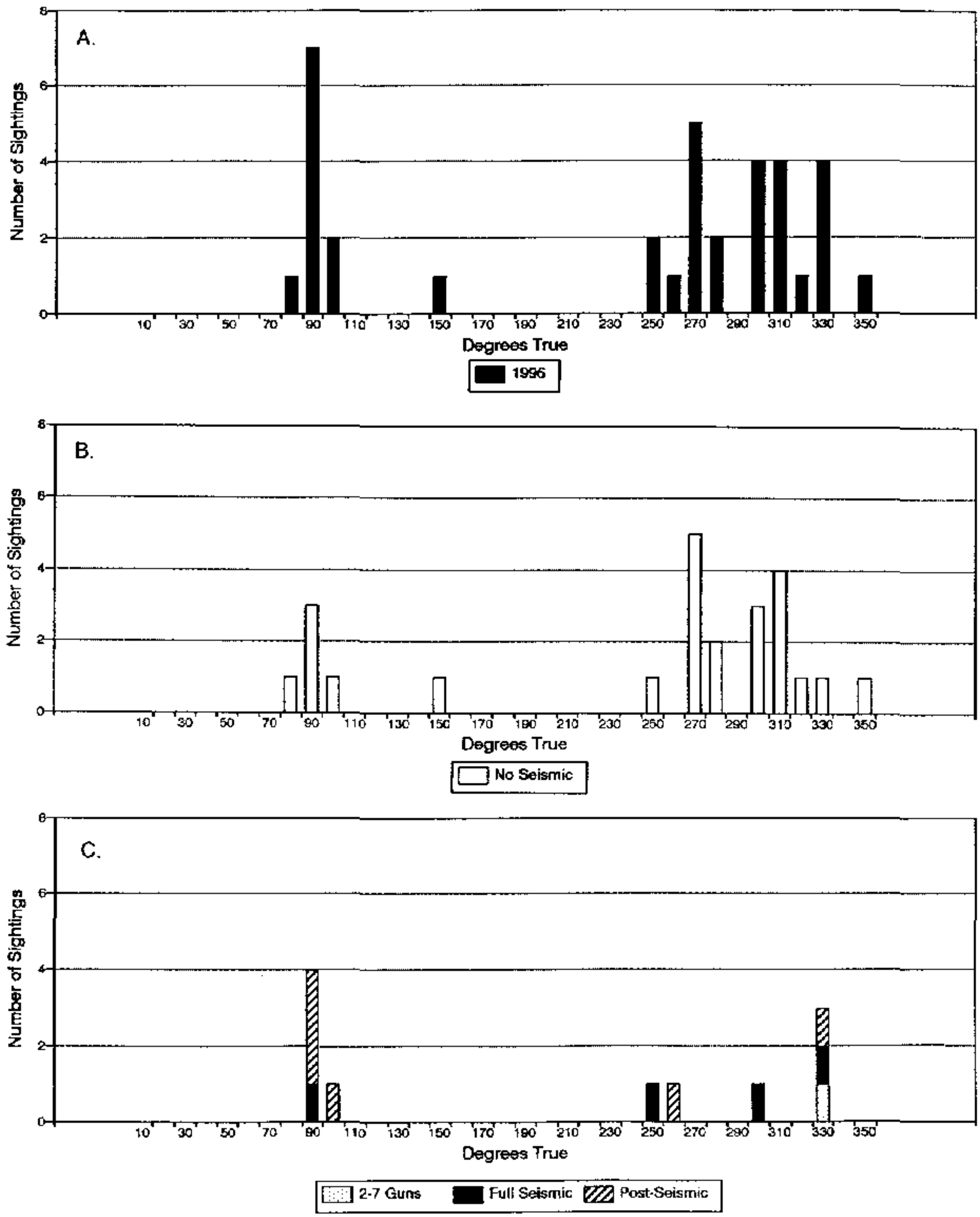


FIGURE 5.40. Headings of bowhead whales recorded as "swimming" in the Northstar region (147°-150°30'W) during late summer/autumn of 1996 comparing *(A)* all periods, *(B)* periods with no seismic, and *(C)* periods with partial array seismic, full array seismic, and post-seismic. The single partial array case also occurred during a "post-seismic" period. Based on sightings during "Transect" flying by LGL and MMS; each sighting counted once regardless of number of whales in group. Labels along the x-axis represent the maximum heading within a 10° range, e.g. "90" represents 81°-90°T.

The headings of "swimming" bowheads were bimodal both with and without seismic exploration (Fig. 5.40B,C). Without seismic, 17 bowheads or groups (71%) were oriented to the W or NW and seven were oriented in other directions, mainly E (vector mean 301°T ± ang. dev. 59°; Fig. 5.40B). With seismic, six bowheads or groups (55%) were heading W or NW and five were heading E (16°T ± ang. dev. 71°; Fig. 5.40C). The proportions of sightings oriented to the W or NW vs. other directions were not significantly different (71% vs. 55%; χ^2=0.89, df=1, P>0.3). Also, although a lower percentage of the "swimming" bowheads were traveling W or NW during times classified as "seismic", only one of the five cases of eastward swimming with "seismic" was actually during a period of seismic operations. The other four were during post-seismic periods (<3.5 h after active seismic operations; Fig. 5.40C).

If the headings of bowhead sightings in the Northstar region during 1996 were influenced by the presence of seismic activity, then it might be expected that bowheads in different locations relative to Northstar might have exhibited different headings. In particular, bowheads farther from shore—and therefore farther from the source of seismic noise—might show tendencies to head in different directions than those closer to shore. Also, bowheads in the eastern portion of the study area (approaching Northstar) might travel in different directions than those in the western portion of the study area (passing or past Northstar). We compared the headings of bowhead sightings inshore and offshore of the 30-km-from-shore line, and east and west of a N-S line located at 148°10'W (*cf.* Fig. 5.7). We used the 221°-330° category mentioned above to represent typical or expected headings. These analyses did not include the headings of any bowheads observed after 20 September, and therefore did not include any late season headings obtained more than two days after the end of the 1996 Northstar seismic exploration season.

The headings of bowhead sightings in offshore and inshore parts of the study area during 1996 are compared in Figure 5.41, considering "swimming" bowheads only. In waters >30 km from shore, the vector mean heading was 312°T ± ang. dev. 55° (n=14, Fig. 5.41A). In these offshore areas, 11 of 14 (79%) of the headings were in "expected" W and NW directions. In waters ≤30 km from shore, the vector mean heading was 315°T ± ang. dev. 72° (n=21, Fig. 5.41B). In nearshore waters, 12 of 21 (57%) sightings were heading in "expected" W and NW directions. These percentages are not significantly different (79% vs. 57%; χ^2=0.89 with Yates correction, df=1, P>0.25).

Bowhead headings in eastern and western portions of the study area are compared in Figure 5.42, considering "swimming" bowheads only. Only 7 headings were recorded in the eastern region (Fig. 5.42A). The vector mean heading for these sightings was 305°T with a relatively low angular deviation of 23°. All headings in this small sample were in the "expected" W and NW directions. Most (28) of the 1996 headings were recorded west of the N-S dividing line at 148°10'W (Fig. 5.42B). The vector mean heading was 321°T ± ang. dev. 72°, indicative of a wide scatter in headings. In this region, 16 of 28 (57%) sightings were heading in "expected" W and NW directions vs. 12 (43%) traveling in "other" (primarily easterly) directions. This east-west difference was statistically significant (Fisher's Exact Test, two-tailed P=0.033).

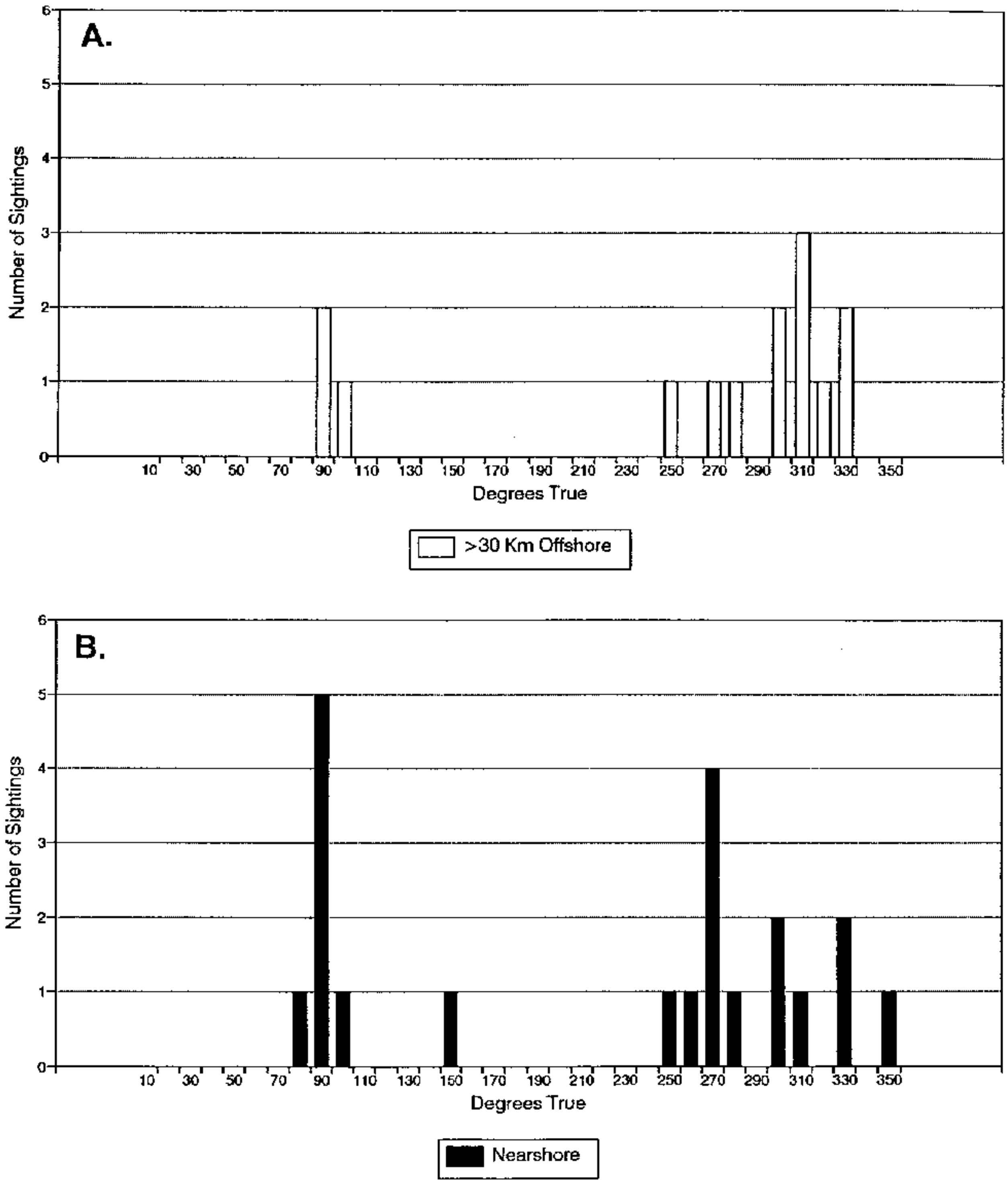


FIGURE 5.41. Headings of bowhead whales recorded as "swimming" in the Northstar region (147°-150°30'W), 1-20 September 1996, comparing headings ***(A)*** >30 km from shore vs. ***(B)*** ≤30 km from shore. Otherwise plotted as in Figure 5.40.

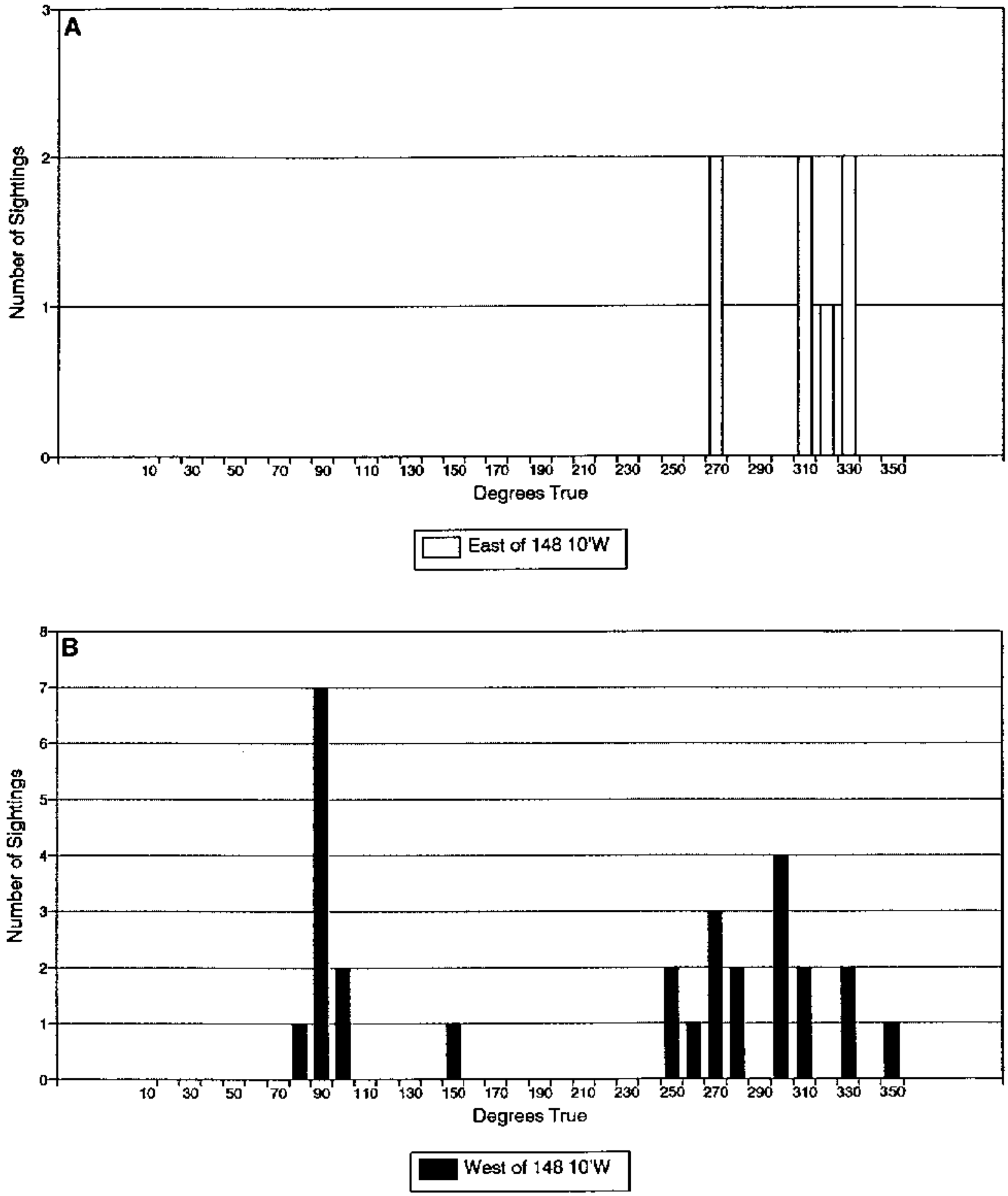


FIGURE 5.42. Headings of bowhead whales recorded as "swimming" in the Northstar region (147°-150°30'W), 1-20 September 1996, comparing headings *(A)* east of 148°10' vs. *(B)* west of 148°10'. Otherwise plotted as in Figure 5.40.

Given this apparent east-west difference, it is important to examine how many of the eastern and western sightings were during "seismic" periods. During the 1996 "Transect" surveys, there were 11 sightings of bowheads "swimming" on known headings during "seismic" periods: five sightings during periods of active seismic work (full- or partial array), and six during post-seismic periods. Only 1 of these 11 sightings was in the eastern region, and it was during a post-seismic period (heading 330°T). Of the five "active seismic" sightings in the western region, one was heading east (90°T) and four were heading W or NW (260°-330°T). The five post-seismic headings in the western region consisted of four easterly (90°-100°T) and one westerly (260°T) heading. This concentration of easterly headings among such a small sample of post-seismic headings is intriguing. However, all post-seismic sightings in 1996 were from surveys on the afternoon of 18 September (Fig. 5.19; Table 5.3). As such, there is some question about the statistical independence of these observations.

Headings in 1996 vs. Other Years.—The high percentage (34%) of the traveling bowheads that were heading in directions other than west or northwest during the late summer and autumn of 1996 (Fig. 5.43A) seemed unusual. However, further analysis showed that, in the Northstar region, bowheads seen during late summer and autumn of other years also were swimming in "other" directions more often than might be expected.

In the late summer and autumn of 1994 and 1995 (light ice years with nil/little industrial activity), headings were determined for 38 bowhead sightings in the Northstar region. Of these sightings during MMS and LGL "Transect" surveys, 28 (74%) were recorded as "swimming". The vector mean heading of the swimming whales was 267°T ± ang. dev. 56°. Of those, 18 (64%) were heading in the "expected" W and NW directions (221°-330°T). Ten (36%) were heading in other directions, but none of those were heading directly east (Fig. 5.43B). The percentages of headings oriented W or NW vs. other directions were very similar during 1994-95 as compared with 1996 (64% vs. 66%; χ^2=0.02, df=1, P>0.75). This comparison is limited in that 1994 contributed only one of the headings observed during the 1994-95 period. Thus, the comparison is basically a comparison of two years, 1995 with little industrial activity vs. 1996 with frequent seismic exploration.

During the 1979-96 period there were 5 years, including 1996, that were identified as years with light ice conditions *and* substantial industrial activity. During these years headings were observed for 95 bowhead sightings, of which 63 (66%) were "swimming". The vector mean heading of the swimming whales was 292°T ± ang. dev. 58° (Fig. 5.43C). Of these 63 headings, 44 (70%) were in "expected" W and NW directions and 19 (30%) were in "other" directions. The percentage oriented W or NW did not differ significantly from that observed during the 1994-95 light ice years with little/nil industrial activity (70% vs. 64%; χ^2=0.08, df=1, P>0.75). However, as noted above, this comparison is limited by the fact that the data from the 1994-95 period are almost entirely from 1995.

In summary, the bimodal distribution of headings observed among "swimming" bowheads in the Northstar region during 1996 initially seemed surprising. However, it was not significantly different from the distributions in 1994-95, when there were no offshore

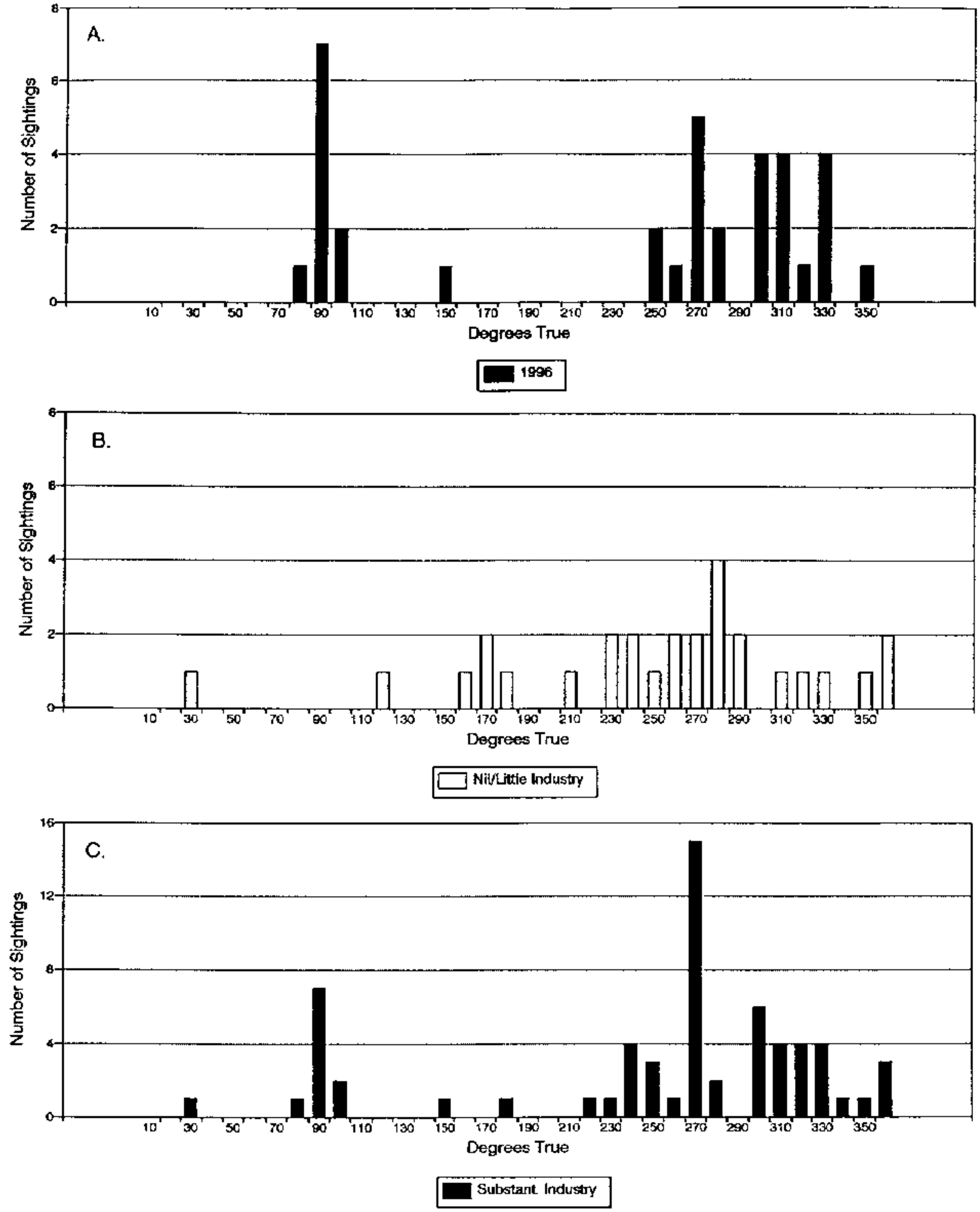


FIGURE 5.43. Headings of bowhead whales recorded as "swimming" in the Northstar region (147°-150°30'W) during late summer/autumn comparing *(A)* 1996, *(B)* light ice years with nil/ little industrial activity (1994-95), and *(C)* five light ice years with substantial industrial activity (1982, 1987, 1989, 1990 and 1996). Otherwise plotted as in Figure 5.40.

industrial activities in the area. Likewise, headings during five years with substantial offshore industrial activity did not differ significantly from those during 1994-95. In 1996, the distributions of headings during seismic and no-seismic periods were similar, as were the distributions for bowheads within vs. beyond 30 km from shore. One 1996 result that might be indicative of a seismic effect was that, based on a very small sample, bowhead headings in eastern and western portions of the study area differed significantly, with more bowheads heading in "other" directions in the western portion.

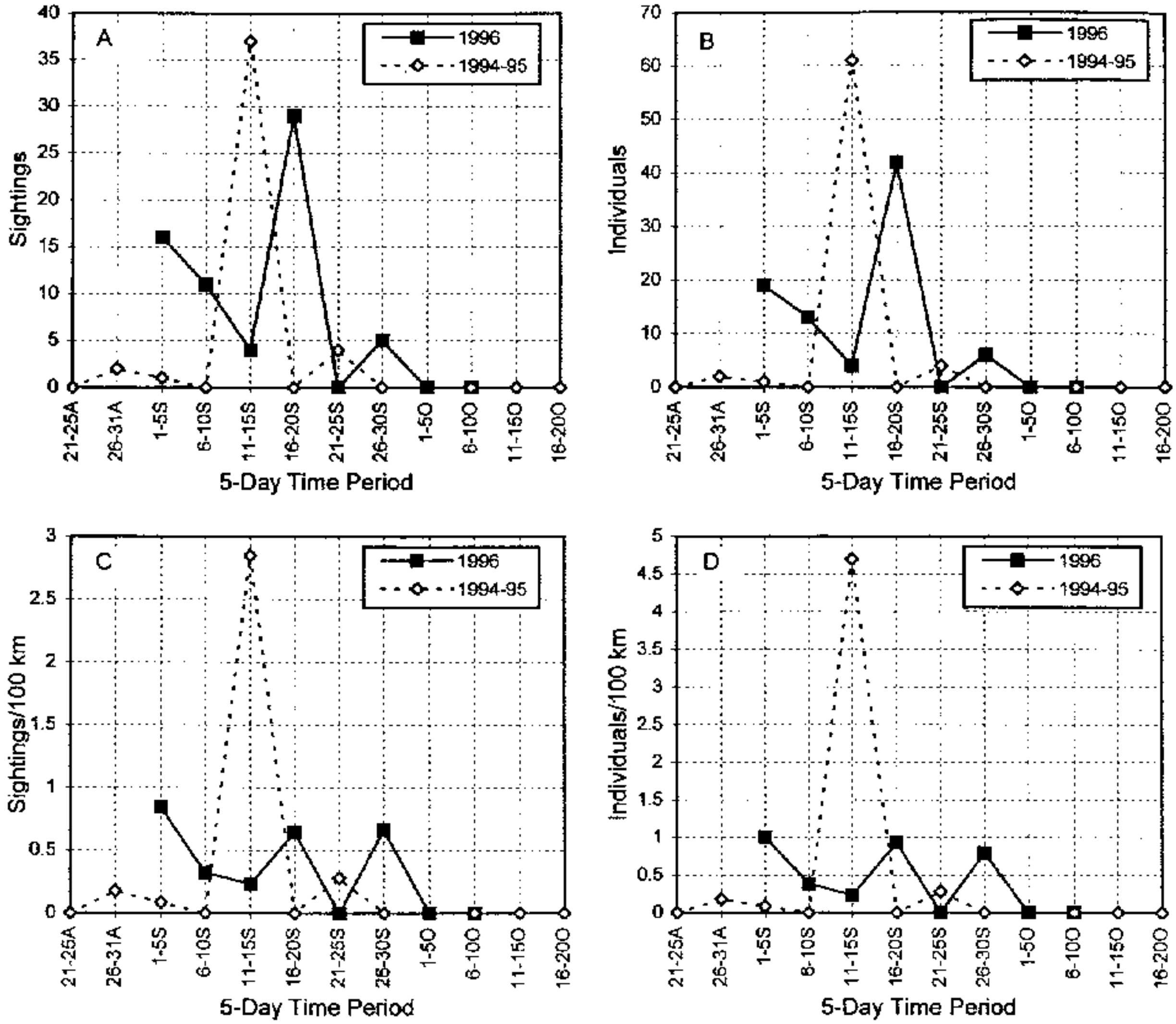
5.3.5 Migration Timing

Taken together, the BPXA/LGL and MMS aerial surveys in the Northstar area during 1996 extended from 2 September to 7 October. The seasonal timing of bowhead sightings during this period was examined using data that include poor sighting conditions. Peak numbers of bowhead sightings (29) and individuals (42) were recorded during the 5-day period from 16 to 20 September (Fig. 5.44). However, survey effort was also highest during that period (Fig. 5.44E). When the data were standardized by survey effort, the number of sightings per 100 km of survey was marginally higher during the 1-5 September period, when there were 0.8 sightings/100 km and 1.0 individuals/100 km (Fig. 5.44C,D). Overall, bowhead numbers in the Northstar region, averaged by 5-day periods, seemed fairly steady during the 1-30 September period, although no bowheads were seen during the 21-25 September period when there was little survey effort (295 km).

In light ice years with little or no offshore industrial activity in the central Alaskan Beaufort Sea (1994-95), the seasonal pattern of bowhead sightings in the Northstar region was hard to discern because of irregular and infrequent survey coverage. There was <500 km of surveys per five day period during 3 of the 6 five-day periods in September 1994-95, and minimal coverage after late September (Fig 5.44E). However, during the 11-15 September period of 1994-95, very high bowhead sighting rates were recorded: 2.85 sightings/100 km and 4.6 individuals/100 km (Fig. 5.44C,D). These sighting rates were heavily influenced by the unusually large number of sightings during MMS surveys in 1995. The very restricted period (11-15 Sep.) when substantial numbers of bowheads were recorded near Northstar during 1994-95 is probably related to the limited and irregular survey coverage in the Northstar area during those years.

Bowhead sightings during light ice years with substantial industrial activity in the central Alaskan Beaufort (1982, 1987, 1989, 1990, and 1996) peaked in the 16-20 September period; numbers of individuals peaked during the 21-25 September period (Fig. 5.45A,B; periods of poor sightability excluded). After standardizing for survey effort, the highest rates of sightings/100 km and individuals/100 km both occurred during the 21-25 September period.

The period with peak sighting rates was about 10 days later during light ice years with substantial industrial activity (21-25 Sept) than during light ice years with nil or little industrial activity (1994-95). This difference is consistent with the hypothesis that industrial activity delays bowhead migration. However, as noted above, the apparent migration peak observed in the 11-15 September period of 1994-95 may have been an artefact of limited or



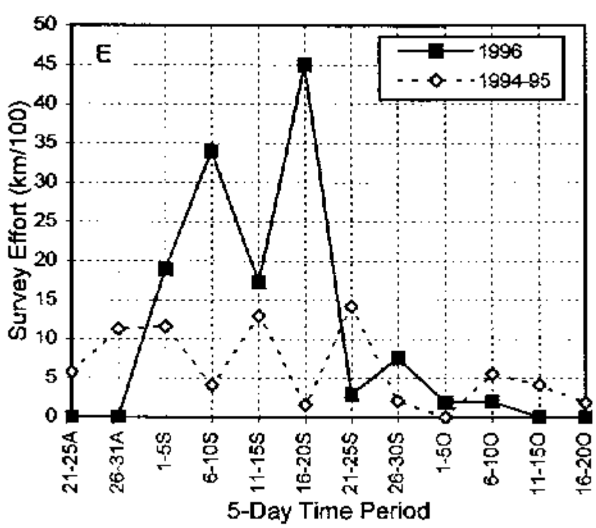
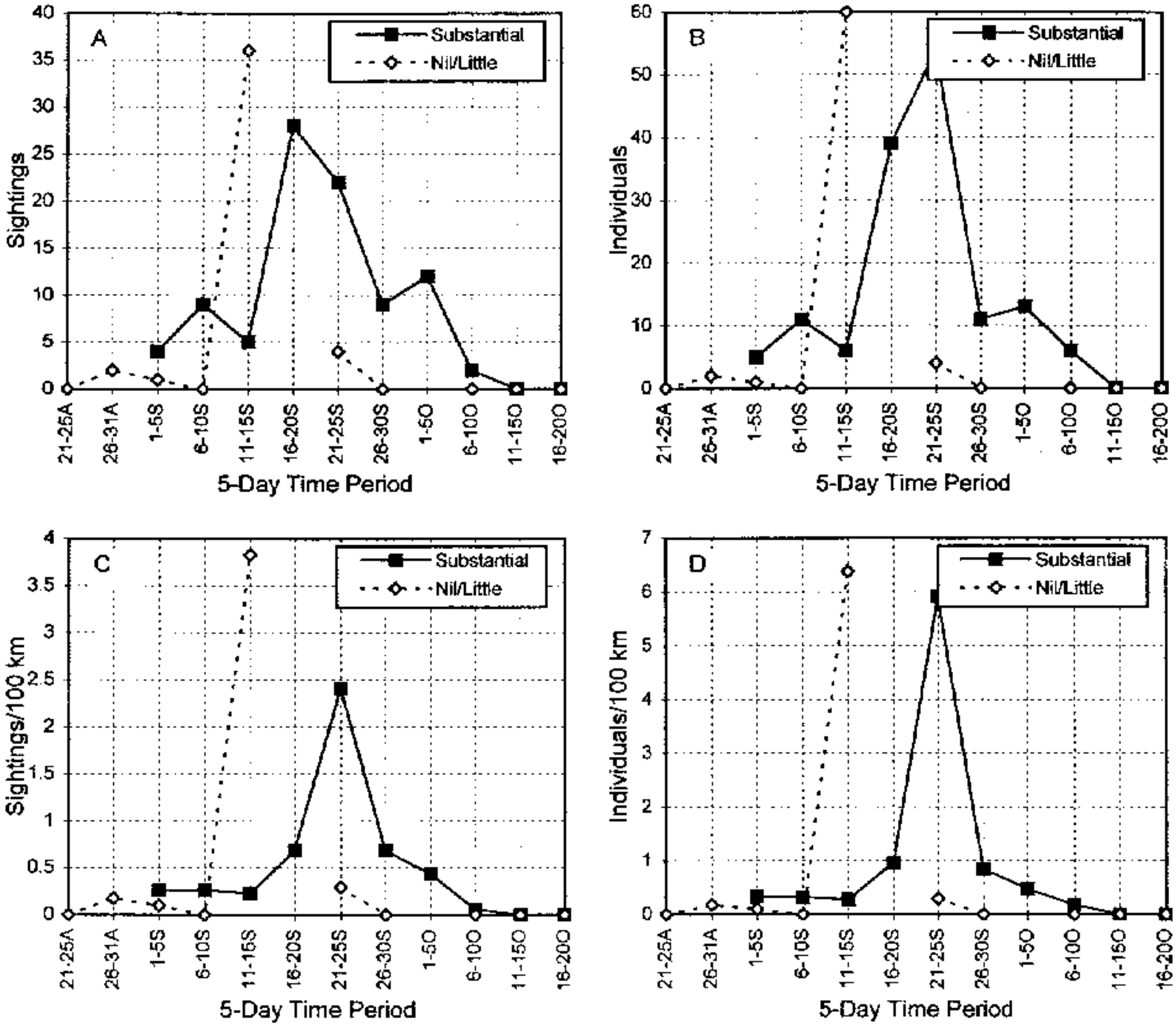


FIGURE 5.44. Seasonal pattern of bowheads in 1996 vs. two light ice years with little/nil offshore industrial activity (1994-95), including periods of poor sightability. Based on LGL and MMS "Transect" aerial surveys in the Northstar region of the central Alaskan Beaufort Sea (147°-150°30') during late summer/autumn. Includes ***(A,B)*** sightings and individuals by 5-day period, ***(C,D)*** sightings and individuals per 100 km of surveying, and ***(E)*** "Transect" survey effort, in 100s of km.



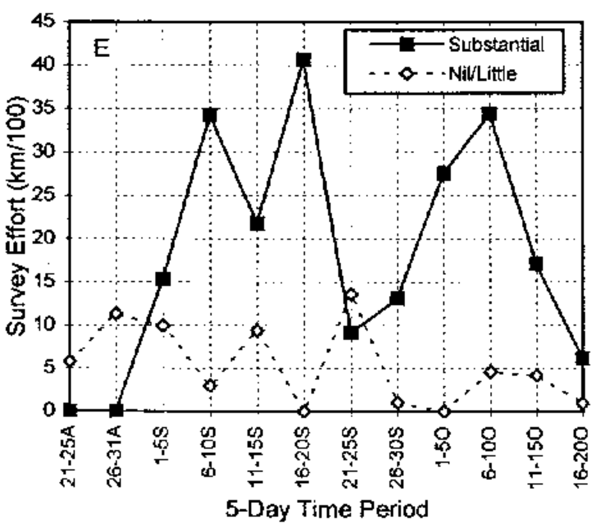


FIGURE 5.45. Seasonal pattern of bowheads in two light ice years with nil/little offshore industrial activity (1994-95) vs. five light ice years with substantial offshore industrial activity (1982, 1987, 1989, 1990, 1996), excluding periods of poor sightability. Otherwise plotted as in Fig. 5.44.

no survey effort during critical 5-day periods (Fig. 5.45E). No conclusions about effects of industrial activity on timing of bowhead migration can be drawn from these limited data.

Peak sighting rates/100 km were somewhat lower in light ice years with substantial industrial activity than in those with no or little industrial activity (2.4 vs. 3.8, respectively). However, peak numbers of individuals/100 km were similar (5.9 vs. 6.4).

It should be noted that some bowhead whales were apparently in the Northstar area before the first aerial survey by MMS on 2 September 1996. Bottom-mounted acoustic recorders (see Chapter 3) were tested seaward of Northstar during the 25-28 August 1996 period. Bowhead whale calls were detected during each of those four dates, with substantial numbers of calls being heard late on the 27^{th} and on the 28^{th}. Bowheads were also seen within the general Northstar region (147°-150°30') as early as 28 August in 1995 (LGL and Greeneridge 1996) and 31 August in 1992 (Treacy 1993).

5.3.6 Bowhead Call Counts

Bottom-mounted acoustic recorders operated simultaneously at sites offshore from Northstar and from Narwhal Island (45 km ESE of the Northstar recorder) from 31 August to 14 September 1996 (see Chapter 3). The recorders were near the 25 and 31 m depth contours, respectively. Both were in the zone that we define as being 20-25 km from the general trend of the shoreline (Fig. 5.7). The Northstar recorder was, in fact, 24 km offshore of the closest barrier island and 15 km from the closest part of the seismic exploration area. The Narwhal Island recorder was actually only 14 km north of that island (and 20 km ENE of Cross Isl.), but was in slightly deeper water than the Northstar recorder (Fig. 5.7).

Technicians at Greeneridge Sciences Inc. listened to the complete sequence of data from each recorder. They detected 6920 bowhead calls in the recordings from the Northstar recorder and 17,634 calls in the recordings from the Narwhal Island recorder during their 351 h of simultaneous operations on 31 August through 14 September 1996. (The Northstar recorder operated for one additional day, through 15 September, but the extra "unmatched" data from the Northstar recorder are not considered in this section.) The hourly call counts are plotted in relation to date and time in Figure 3.38 (Chapter 3).

The average call count per hour was 19.7 ± s.d. 29.8 off Northstar, vs. 50.2 ± s.d. 59.6 off Narwhal I. Of the 331 hours when call counts at the two sites differed, the count was higher near Narwhal I. on 235 occasions and higher off Northstar on 96 occasions. The difference was highly significant according to a Wilcoxon matched-pairs test on paired hourly counts (nominal $P<<0.001$). This test no doubt overstates the significance level, given that the counts in successive hours are autocorrelated. However, it is obvious that bowhead calls were much more commonly detected off Narwhal Island than off Northstar.

There must have been a real difference in the number of bowhead calls reaching the two recorders. Differences in background noise levels at the two sites cannot account for this:

- Seismic pulses were often detected by the Northstar recorder but were rarely detected (and weak) at the Narwhal Island recorder. However, the durations of the seismic pulses were <1 s at typical intervals of 15-18 s. During periods with seismic, less than 5% of the calls would have been simultaneous with seismic pulses. Masking cannot account for the much lower number of calls detected near Northstar than near Narwhal Island.
- Ambient noise levels were, on average, almost identical at the two sites (Chapter 3).

Bowhead sighting rates in the eastern and western parts of the Northstar area during previous years can be used to examine whether bowheads are normally more common in the eastern portion near Narwhal Island. The Northstar region was subdivided at 148°10', about 10 km east of the Northstar recorder's location (Fig. 5.7). We considered the zone 15-35 km from shore, i.e. from ~8 km inshore to 12 km offshore of the bottom recorder locations. In 1994-95, light ice years without much offshore industrial activity, bowheads were seen more commonly in the west than the east zone: 3.74 vs. 1.96 individuals/100 km. In the 1979-95 period as a whole, bowhead densities in the two zones were similar: 0.48 indiv./100 km in the west vs. 0.54 indiv./100 km in the east. Thus, sighting data from aerial surveys in prior years do not provide any basis for expecting a higher number of bowheads, and a higher call count, near the Narwhal Island recorder (east) than near the Northstar recorder (west).

The number of calls detectable per hour near Northstar was lower during hours when seismic pulses were detectable at that location (avg 12.6 calls/h, n=174) than when not detectable (avg 26.8 calls/h, n=177). If the hourly counts are treated as independent, this difference is highly significant (Mann-Whitney test, nominal $P<0.001$). A randomization test taking the autocorrelation structure into account also showed a significant decrease in calls with seismic pulses ($P<0.02$, N.S. Altman, Biometrics Unit, Cornell Univ., pers. comm.).

To help assess whether the above difference was attributable to the seismic sounds or to some other factor, it is useful to examine the relationship between the Northstar and the Narwhal Island counts during times with and without seismic. The number of calls detectable per hour was significantly lower near Northstar than near Narwhal Island in the absence of seismic as well as in the presence of seismic (nominal $P<0.001$ in each case; Wilcoxon matched-pairs tests). However, the Northstar/Narwhal difference in the number of calls per hour tended to be substantially greater with seismic than without seismic[7]:

	Northstar	Narwhal	Hours
Seismic heard:	12.6 ± s.d. 24.4	56.2 ± s.d. 67.9	n=174
No Seismic heard:	26.8 ± s.d. 32.8	44.4 ± s.d. 49.7	n=177

[7] The above results are based on call data from the 31 Aug. through 14 Sep. period. We wondered whether the lower average call counts near Northstar might have been caused by including data from the start of the bowhead migration season, before the vanguard of bowheads may have reached the Northstar area (*cf.* Fig. 3.38). However, the Northstar call counts again averaged higher without seismic than with seismic when we considered only the data from 3 to 14 Sep. (avg. 32.5 calls/h without seismic, n=143 hours; avg 15.3 calls/h with seismic, n=136 hours).

A simple (but not very powerful) way to examine these data is with a sign test. With audible seismic pulses off Northstar, the Northstar count exceeded the Narwhal count during only 37 of 174 hours (21%). Without seismic pulses off Northstar, the Northstar count exceeded the Narwhal count during 59 of 177 hours (33%). Assuming independence of hourly counts, this difference is significant (χ^2=5.84, df=1, nominal P<0.05).

There was a weak overall positive correlation between the hourly call counts at the two sites (Spearman rank correlation 0.190, n=351). This trend was statistically significant if the hourly counts are assumed to be independent (nominal P<0.001). This trend was almost entirely attributable to hours without seismic, when the Spearman correlation was 0.353 (n=177, nominal P<0.001; see Fig. 5.46A). During hours with seismic, there was no obvious correlation between call counts at the two sites (r_s=0.061, n=174, nominal P>0.2; Fig. 5.46B). Inspection of Figure 5.46A vs. 5.46B confirms that the Northstar/Narwhal ratio tended to be lower with seismic than without seismic. Note the higher proportion of the hourly points below the diagonal in Fig. 5.46B than in Fig. 5.46A. Also note that the number of hours with no detectable calls at Northstar but some calls at Narwhal was much higher when seismic pulses were audible near Northstar.

In summary, the number of bowhead calls detectable per hour near Northstar was lower during hours when seismic pulses were detectable on the Northstar recorder. This was true both overall and relative to the paired Narwhal Island count. Ensonification of waters near Northstar by seismic sounds apparently had one or both of the following effects: it reduced the number of calls emitted by an average bowhead per hour, and/or reduced the number of bowheads within a several kilometer distance of the recording unit off Northstar.

Previous studies have shown that bowhead whales often continue to emit their usual repertoire of call types when exposed to seismic pulses. However, calling rate may tend to somewhat lower in the presence of seismic pulses (Richardson et al. 1986; Koski and Johnson 1987:114). Thus, the reduced numbers of calls heard during periods of seismic in this study might represent a change in the rate of calling by individual bowheads exposed to seismic sounds. However, it might also represent a reduction in the number of bowheads present nearby, or some combination of the two.

5.3.7 Sounds Received Near Bowheads

LGL's aerial observers obtained nine bowhead sightings, each involving a single bowhead, at times when seismic exploration was underway with a partial array (2 sightings) or full array (7 sightings; Fig. 5.23). These sightings were made on 9, 10, 15, 17 and 18 September. On 9 September the only sighting was 74 km east of the seismic activities (Fig. 5.13), and no measurements of sounds received near the whale were obtained. On each of the other four days, a sonobuoy was dropped near the bowhead that was seen closest to the seismic activities on that date (ranges 25-66 km). In total six sonobuoys were dropped near bowheads at ranges 25-66 km from the seismic boat while either "full array" or "partial array" seismic was being conducted.

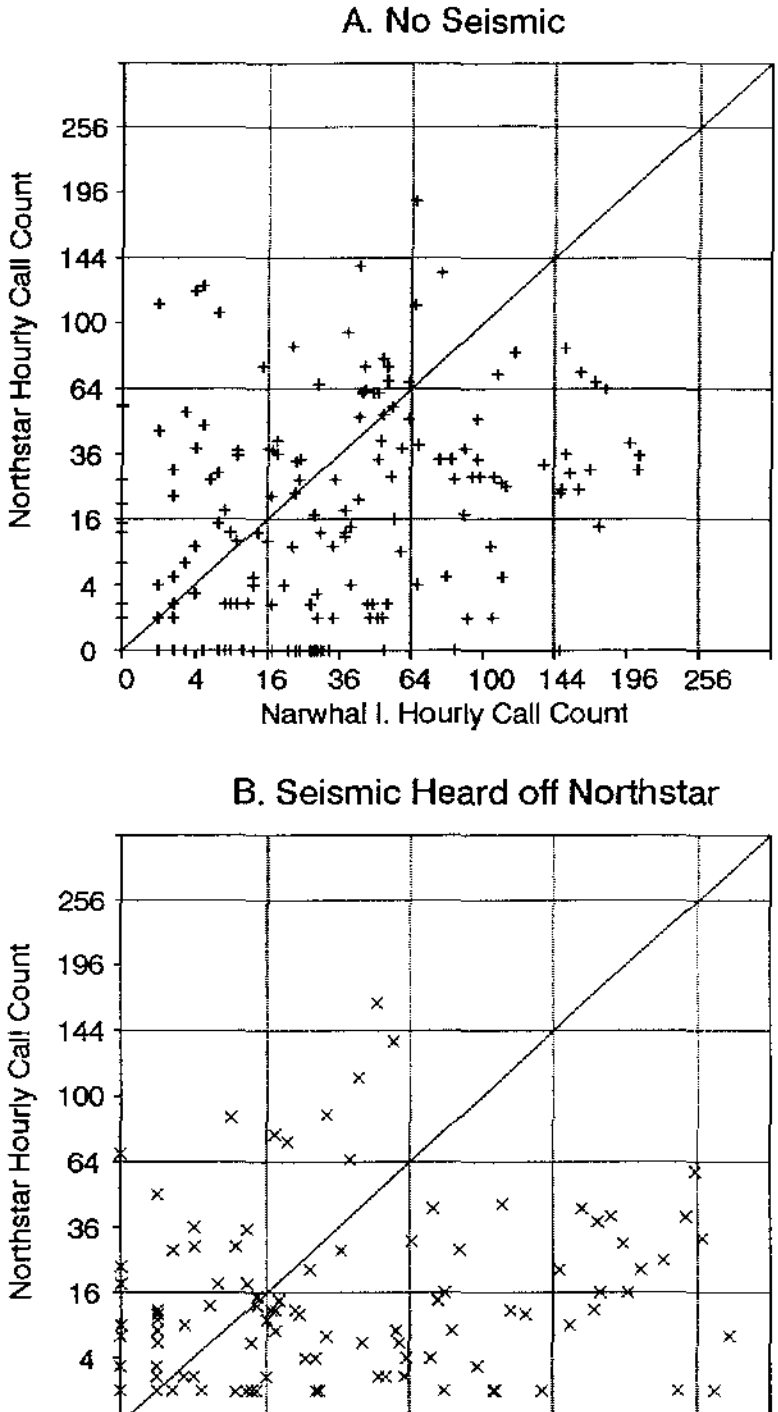


FIGURE 5.46. Number of bowhead calls detected per hour by bottom-mounted acoustic recorders off Northstar vs. Narwhal Isl. during hours when seismic pulses *(A)* were not detectable and *(B)* were detectable off Northstar (square root transformed). Paired hourly call counts were obtained from 31 Aug. to 14 Sep. 1996. Points above and below diagonal represent hours when Northstar call count was more and less, respectively, than the Narwhal count.

Seismic sounds were undetectable or barely detectable near four of these whales. Those four whales were 27-66 km from the seismic source vessel.

The strongest sound pulses received near any of these six bowheads were recorded near two whales seen on 10 and 15 September. On 10 September, peak and mean levels of seismic pulses near a whale 24-28 km NE of the "full array" (Fig. 5.14) were 120-122 and 109-114 dB re 1 µPa, respectively. On 15 September, peak and mean levels of seismic pulses near a whale 41-42 km WNW of the "partial array" (Fig. 5.17) were 119-121 and 101-102 dB re 1 µPa, respectively.

Thus, the strongest seismic pulses measured near bowheads observed during this project had peak levels near 122 dB and rms levels near 114 dB re 1 µPa. Levels received in the bowhead migration corridor vary as the seismic boat moves back and forth along its 7.3-km source lines from shallower to deeper water and back to shallow water. Also, some of the bowheads presumably were not at their closest points of approach to the seismic operation at the times when we sighted them. Thus, we probably did not record the strongest sounds received by the bowheads that were sighted during this project.

Figure 5.47 shows the estimated rms (= "mean square") levels of seismic pulses as they would be received at various distances directly offshore from Northstar, assuming that the full array was operating 10 km from shore (i.e. near the northern edge of the area of seismic operations during 1996). The estimated received level curves in this graph are the same as the "good propagation", "typical propagation" and "poor propagation" curves in Figure 3.35 (Chapter 3), but plotted on a linear rather than a logarithmic distance scale, and plotted with respect to a source located 10 km offshore. Also shown on Figure 5.47 are the 5th, 50th and 95th percentile ambient noise levels in the 50-400 Hz band (again from Fig. 3.35). The 50-400 Hz band contains most of the pulse energy as received at long range.

The distances offshore at which the three received level curves drop below these ambient noise levels are the approximate distances out to which bowhead whales should be able to hear the seismic pulses under various conditions of sound propagation and ambient noise. With poor, typical and good propagation, the received pulse levels are expected to drop below the median ambient level at ranges of 32, 46 and 68 km offshore if the airgun array is 10 km offshore. At a time with low ambient noise, the corresponding distances could be on the order of 52-108 km. At a time with high ambient noise, these distances could be on the order of 27-56 km. It is emphasized that these are the estimated distances offshore at which the seismic pulses would change from faintly audible to inaudible.

Available data indicate that bowheads usually do not react overtly (if at all) to the weak pulses received at such long distances. However, during one prior study, there was evidence of subtle but replicable effects on surfacing-respiration-dive cycles at distances up to 54-73 km (Richardson et al. 1986). In that study, some seismic sources were more powerful and were operating in deeper water. In addition, single cases of possible seismic-related changes in behavior have been observed or suspected at even longer distances (Reeves et al. 1983:24; Koski and Johnson 1987:114). Given the natural variability in bowhead behavior, it is impos-

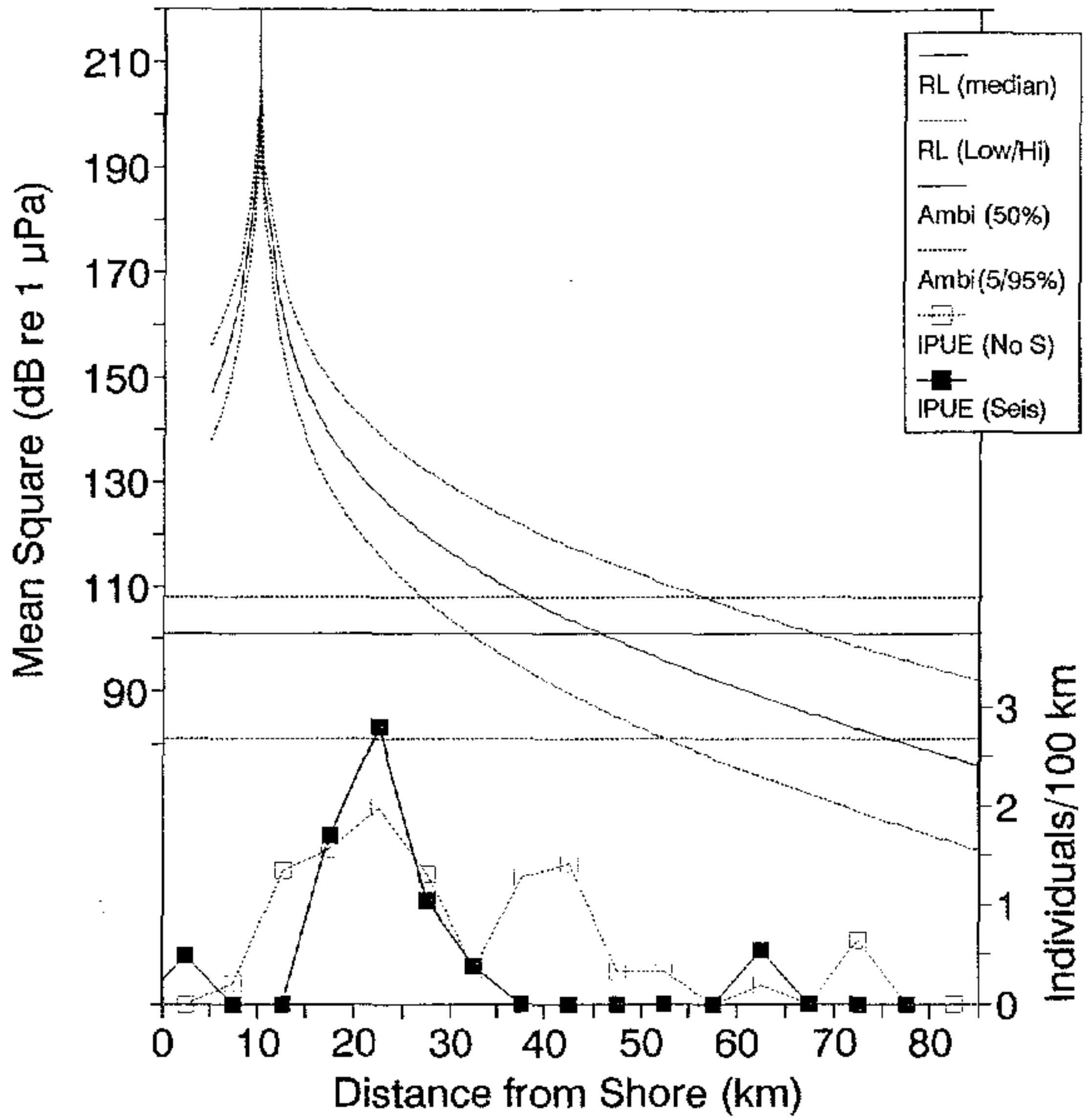


FIGURE 5.47. Estimated received levels of seismic pulses in the bowhead migration corridor when the full 11-airgun array was operating 10 km offshore. Red curves show the expected range of received levels vs. distance from shore; blue horizontal lines show the expected range of ambient noise levels (50-400 Hz band; from Fig. 3.35). Curves at the bottom, adapted from Fig. 5.28D, show relative numbers of bowhead whales sighted in various 5-km-from-shore categories at times during 1996 with and without seismic (filled and open squares, respectively).

sible to know whether any one such case represents a real reaction to seismic. Replicated observations are needed.

The curves near the bottom of Figure 5.47 show the number of bowheads seen per 100 km of aerial surveys within each 5-km distance from shore band, including observations under poor sightability conditions. These are the same data as shown in Figure 5.28D, but plotted by 5-km rather than 10-km intervals. Periods potentially affected by seismic (including 3.5-h post-seismic period) and not potentially affected by seismic are distinguished. As noted previously, there was a possible seaward displacement during seismic periods, but the sample size was small. In any case, most bowheads passing Northstar during "seismic" periods were 15-30 km offshore. With a seismic vessel operating 10 km from shore, received pulse levels 15-30 km offshore would be above ambient levels for most combinations of distance from shore (out to 30 km), propagation conditions, and ambient noise level. The only exceptions would be whales that passed Northstar 27+ km offshore at times with poor propagation and high ambient noise (Fig. 5.47). They might not have been able to hear the pulses.

Whales traveling west 15 km offshore could have been exposed to rms pulse levels approaching (but not exceeding) 160 dB re 1 µPa if they passed that area when the airgun array was operating near the northern edge of the seismic operations area (10-11 km offshore). Whales traveling west <15 km offshore could have been exposed to levels ≥160 dB if the animals did not deflect away from the seismic vessel. As shown by the bottom curves in Figure 5.47, some bowheads were seen <15 km from shore without seismic but (with one exception)[8] not with seismic. Note that rms levels as used here (averaging over the pulse duration) are about 10 dB lower than the peak levels normally referenced by geophysicists.

5.3.8 Estimated Bowhead "Take by Harassment"

In the following analyses we have assumed that the received rms pulse levels from the seismic source could be as high as 180 dB re 1 µPa at distances as great as 1 km (Chapter 3). Also, it is assumed that received levels may exceed 160 dB re 1 µPa out to a maximum radius of 4.9 km. On average, however, the rms pulse levels are expected to diminish below 160 dB re 1 µPa at a radius of ~3.6 km from the source (Chapter 3).

180 dB Criterion.—NMFS (1995) concluded that noise pulses from a nearby seismic vessel might affect the hearing abilities of baleen whales if received levels exceed 180 dB re 1 µPa. Given this assumption, the Incidental Harassment Authorization (as modified on 6 Sep. 1996) called for immediate shutdown if cetaceans were detected within 750 m during operation of the airgun array, or within 650 m during operation of a single airgun. Subsequent analysis has shown that received levels were, at times, 180 dB re 1 µPa or more at radii as great as 1 km. In fact, no bowhead whales were seen by the marine mammal observers

[8] One bowhead was seen in the zone we classify as 0-5 km from the "general trend of the shoreline" during a period with partial-array seismic on 15 Sep. 1996 (Fig. 5.17; Table 5.3). This whale was 42 km WNW of the seismic vessel at the time. Its CPA to the operating seismic vessel is unknown.

or other personnel based on the seismic source vessel. The observers were on duty and watching for marine mammals at all hours when airgun operations were underway, for at least 30 min before all planned startups of the airguns, and at some times with no airgun operations. Also, aircraft-based observers saw no bowheads within 20 km of the operating source vessel (Table 5.3; Fig. 5.39).

It is recognized that some bowheads might have been present near the source vessel during periods of darkness or poor visibility, or below the surface. However, bowheads tend to avoid the immediate vicinity of operating seismic vessels (Richardson et al. 1986; Ljungblad et al. 1988). Thus, it is unlikely that any bowheads occurred within 1 km of BPXA's operating seismic vessel. It is also assumed that any bowheads present near the inactive vessel during poor visibility conditions would move away if a single airgun started and then additional airguns began to operate during a "ramp-up" toward full-array operation.

Thus, no bowheads (or other cetaceans) were seen within the 750 m "shutdown radius", or within the somewhat larger 1 km "maximum 180 dB radius", at any time during the Northstar seismic program. It is unlikely that there were unseen bowheads within 1 km of the operating source vessel.

160 dB Criterion.—Recent NMFS practice involving impulsive sounds such as seismic has been to assume that a "take by harassment" may occur if baleen whales are exposed to received levels of pulsed sounds that exceed 160 dB re 1 µPa. Takes of this type involve avoidance and short-term changes in behavior that occur at distances well beyond those where there is any likelihood of injury to the whales (NMFS 1995; Richardson et al. 1995: 372*ff*).

No Direct Evidence of "Take": The sonobuoy data discussed above showed that none of the bowhead whales seen by the aerial observers were within or near the areas where they might have been exposed to seismic pulses with received levels ≥160 dB re 1 µPa. However, the aerial observers saw only a very small percentage of the total number of bowheads that migrate west past the Northstar region during late summer and autumn. Thus, the lack of observations of bowheads exposed to ≥160 dB seismic pulses does not justify an assumption that no bowheads were exposed to strong seismic pulses.

Bowheads Within 15 km of Shore: The Bering/Chukchi/Beaufort Sea stock of the bowhead whale is currently estimated to contain about **8000 animals** (Zeh et al. 1995; Small and DeMaster 1995). For purposes of estimating take we will assume that all of these whales migrate west either north of or through the Northstar seismic exploration area.

Based on the acoustic measurements obtained during this study, rms received levels of seismic pulses would be ≥160 dB re 1 µPa at distances as great as 3.6 km from the source vessel on average, and as great as 4.9 km at the maximum (Chapter 3). The following assessment assumes that received levels exceeded 160 dB out to a radius of 4 km.

The source vessel conducted seismic surveys ≤11 km north of the "0-km line" shown in Fig. 5.7. Thus, whales that were more than ~15 km offshore relative to the "0-km line" (Fig. 5.7) when passing the operating source vessel would not have been exposed to seismic sounds that exceeded 160 dB re 1 µPa. During 1996 transect surveys with good sightability, 4 of the 65 individual bowheads seen (6.2%) were inshore of the 15-km line shown in Fig. 5.7, and therefore *might* have been exposed to sounds that could elicit short-term changes in behavior (Fig. 5.48C). When the differing amounts of survey effort at different distances offshore (Fig. 5.35B) were taken into account, the percentage of individual bowheads that occurred within 15 km of shore in 1996 is estimated as **7.0%** (Fig. 5.48D).

For several reasons, this 7.0% figure greatly overestimates the percentage of the bowhead population that could have been exposed to 160 dB sounds:

- This percentage does not take into account the bowheads that migrate west through offshore waters, farther north than the northern extent of survey coverage at 71°12.5'.
- Many bowheads migrate past Northstar after the 18 September termination of the 1996 seismic program.
- There were no airgun operations during many of the hours prior to 18 September

Additional complications are that

- this percentage is based on a small number of sightings, and
- if bowheads are displaced offshore by seismic work in nearshore waters, this figure might *under*estimate the percentage of bowheads that would have occurred inshore of the 15-km line in the absence of seismic exploration.

The proportion of bowheads migrating inshore of the 15-km line in years other than 1996 may provide a better basis for estimating the numbers that might have been exposed to seismic pulses with received levels ≥160 dB re 1 µPa in 1996. For this purpose we used the 1994-95 period, which had similar ice conditions to those in 1996, but little or no offshore industrial activity in the Northstar region. During the 1994-95 period none (**0.0%**) of the 67 individuals seen during systematic transect surveys by MMS and LGL in the 147°-150°30'W area were inshore of the 15-km line (Fig. 5.48C).

Proportion of Bowheads Passing by 18 September: The proportion of bowheads passing the longitude of Northstar up to 18 September (the date when 1996 seismic exploration ended) was estimated based on the MMS survey data from 1996. Their surveys extended from 1 September to 9 October. Some whales probably passed Northstar before 1 September: MMS and LGL surveyors saw numerous bowheads in the survey area during the initial 1996 surveys on 2-3 September, and bottom-mounted acoustic recorders seaward of Northstar detected bowhead calls during late August 1996. Also, the migration probably continued after 9 October. Substantial numbers of bowheads were present along the Yukon coast as late as mid-October 1985 (Evans and Holdsworth 1986), the only year when surveys have been conducted that late in Canadian waters. In prior years, some bowheads have been seen in the present study area during mid-late October. In any event, 12 of 29 (**41.4%**) of MMS's 1996

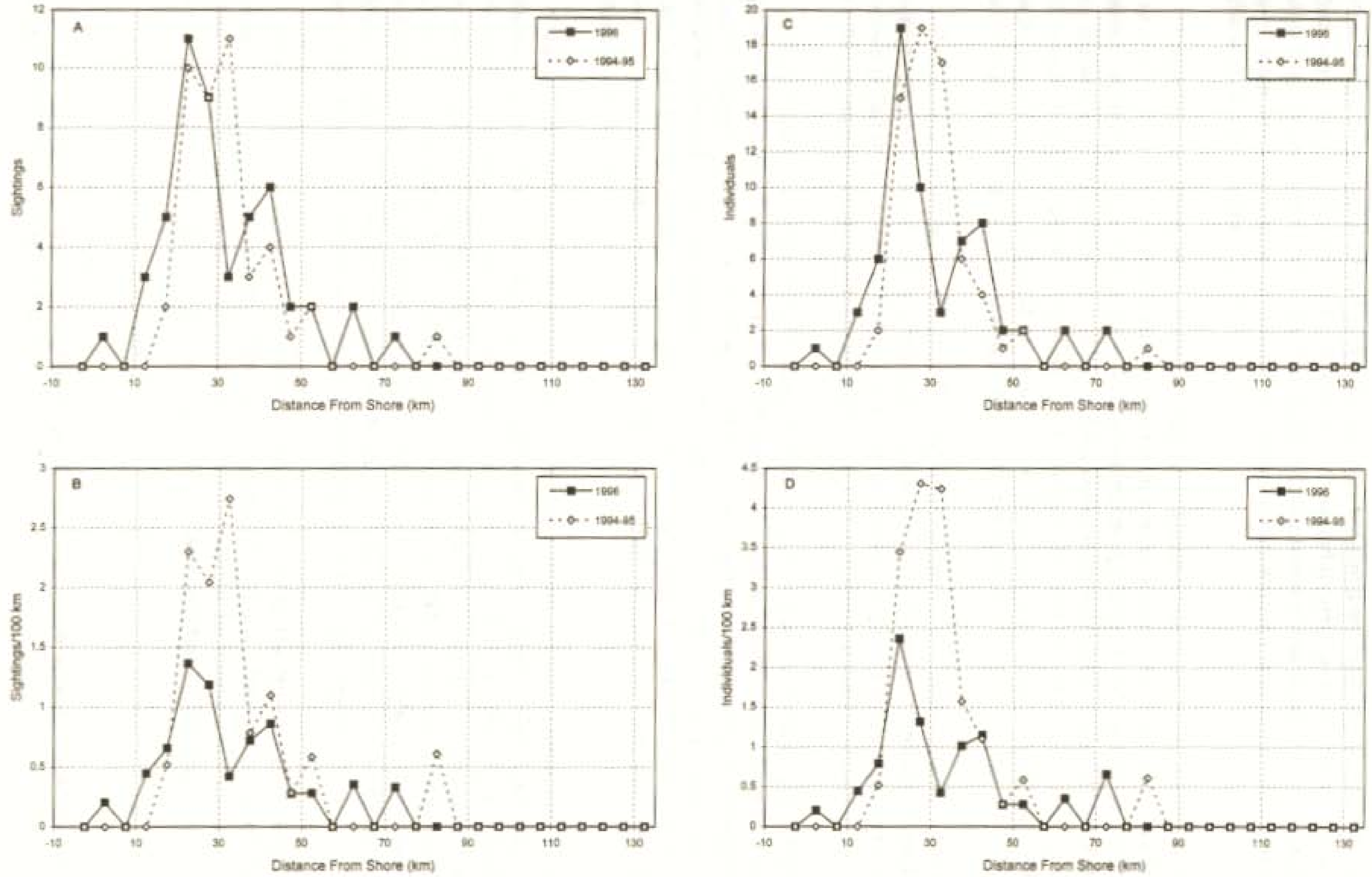


FIGURE 5.48. Distributions of bowheads by 5-km distance-from-shore intervals during late summer/autumn of 1996 vs. 1994-95 (light ice years with nil/little industrial activity), excluding periods of poor sightability. See Fig. 5.35B for survey effort vs. distance from shore, and Fig. 5.36 for the same data plotted by 10-km intervals. Otherwise as in Fig. 5.28.

bowhead sightings in the 146°-151°W region were obtained on dates up to 18 September, the period when seismic was being conducted. If we arbitrarily assume that the number of whales that passed prior to the first survey on 2 September was similar to the number that passed after the last survey on 9 October, then we can assume that about 41% passed prior to the end of seismic operations.

Proportion of Time With Seismic Surveys: During the 1-18 September 1996 period, there were 168 h when seismic survey operations were being conducted and 264 h with no seismic operations. The 168 h includes times when operations with a full or partial array were underway.[9] Thus, strong seismic pulses were being produced during only **38.9%** of the 1-18 September 1996 period. Furthermore, during ~56 h of the 168 h, only a partial array was in use, and the 160 dB radius would have been less than 4 km. Thus, the number of whales that might have been taken is again overestimated.

Proportion of Bowheads Passing During Seismic Surveys: Combining the factors in the two preceding paragraphs, it is estimated that, up to 18 September 1996, about **16.1%** of the bowhead population moved westward past the Northstar seismic survey area during periods with full or partial array seismic operations (0.414 × 0.389 × 100%).

"Worst Case" Estimate of Take: Based on this approach and considering the 1996 survey data, the "worst-case" estimate is that 90 bowhead whales might have encountered seismic pulses as strong as 160 dB re 1 µPa and so could be considered "taken by harassment". This estimate is based on a population size of 8000 whales x 0.0701 for the proportion inshore of 15-km line x 0.161 for the proportion passing during periods with airgun array operations). Based on the 1994-95 survey data, the corresponding "worst case" estimate is 0 bowhead whales (8000 × 0.0 × 0.161).

Allowance for Source Boat's Variable Distance From Shore: These are "worst case" estimates in that they assume that any bowhead inshore of the "15-km line" while seismic work was underway was exposed to seismic pulses ≥160 dB re 1 µPa. This would require that the seismic vessel always be operating about 11 km from shore. In fact, of the area shot during 1-18 September 1996, 70% was <6 km offshore. When the vessel was operating <6 km from shore, received sound levels would be <160 db re 1 µPa at distances >10 km offshore. Thus, the numbers of bowheads exposed to pulses with received levels ≥160 dB were undoubtedly much lower than suggested by the previous paragraph.

The estimates can be made more realistic by making the following assumptions: (1) During the 30% of the time that the vessel operated 6-11 km offshore, some of the whales within 15 km of shore (mostly 10-15 km offshore) would be exposed to levels ≥160 dB re 1 µPa. (2) During the 70% of the time that the vessel operated <6 km from shore, only the

[9] The 168 h excludes an additional 9 h of operations with a single airgun, when the 160 dB radius was much less than 3 km (Chapter 3).

very few whales that might occur within 10 km from shore could be exposed to ≥160 dB levels.

1. During the 30% of the operating time when (1) would apply, the estimated "take by harassment" would be 27 based on the bowhead distribution observed in 1996, and 0 based on the bowhead distribution observed in 1994-95. (These values are 30% of the "worst case" estimates, 90 and 0, derived previously.)

2. To estimate take during the 70% of the operating time when (2) would apply, we need to consider the percentage of the individual whales that migrate within 10 km of shore. This was estimated as **2.20%** based on the 1996 surveys (allowing for varying survey effort at different distances offshore) and **0.0%** based on the 1994-95 surveys (Fig. 5.48D). The total numbers of bowheads passing within 10 km of shore when airguns were operating within 6 km of shore would be ~20 based on the 1996 data (8000 x 0.0220 x 0.161 x 0.70), and 0 based on the 1994-95 data (8000 x 0.0 x 0.161 x 0.70).

Combining (1) and (2), the take estimates based on the "160 dB re 1 μPa criterion" are 47 bowheads based on the distribution observed in 1996 and 0 bowheads based on the sample from light ice years with little offshore industrial activity (1994-95). The latter figure (0) is no doubt an underestimate, as a few bowheads do occur within 15 km of shore in certain years. However, the former figure (47) is an overestimate: it effectively assumes that the seismic boat was operating 6 km from shore whenever it was ≤6 km offshore (70% of the operating hours), and that it was operating about 11 km from shore whenever it was more than 6 km offshore (30% of the operating hours).

Further refinements in the estimates could be made by examining both the bowhead sightings and the seismic survey activities on a finer spatial scale. Allowance could also be made for the fact that the seismic signals undoubtedly attenuate more rapidly when the vessel is in shallow water than when it is in deeper water. However, it does not seem appropriate or necessary to incorporate further levels of refinement and complexity into the estimation process, given

- the many assumptions that are inevitably involved,
- the very small sample sizes for sightings in nearshore waters,
- the fact that the estimated take is already small, and
- the fact that the type of "taking" being discussed is avoidance and short-term behavioral changes with no known long-term consequences to the animals.

Displacement Criterion.—Bowheads whose migration corridor is deflected offshore by a seismic program in nearshore waters could be considered to be disturbed or "taken by harassment". The 1996 Northstar monitoring program found hints of possible offshore displacement of some bowheads during periods of active seismic exploration. The proportion of the bowheads traveling within 20 km of shore was apparently lower during seismic periods (Fig. 5.28). More data are needed to confirm whether this apparent effect was actually caused by the seismic vessel. However, it is instructive to estimate the number of bowheads that might have been "taken by harassment" if bowheads migrating past Northstar within 20 km of shore actually were displaced or otherwise disturbed by the seismic.

Based on 1996 aerial survey results from times without seismic exploration, 19 of 64 (29.7%) individuals seen were within 20 km from shore (Fig. 5.28C). Allowing for varying survey effort at different distances from shore, it was estimated that ~33.5% of the individual bowheads passing through the surveyed area without seismic were <20 km from shore (Fig. 5.28D). During 1994-95, 2 of 68 (2.9%) individual bowheads seen were shoreward of the 20 km line. Corrected for variable survey effort at different distances from shore, ~3.1% of the individual bowheads migrating through the surveyed area were within 20 km of shore during 1994-95 (5.47C,D).

The factors derived earlier for proportions of bowheads passing Northstar by 18 September (**0.414**) and during times with active airguns (**0.389**) apply here as well. Therefore, we estimate that, in 1996, 5.4% of the bowhead population (0.414 × 0.389 × 0.335) would have passed within 20 km of the northern edge of the exploration area while the airguns were in operation if there were no deflection. The comparable estimate based on 1994-95 data is 0.5% (0.414 × 0.389 × 0.03). Applying these proportions to the total estimated number of bowheads (8000) passing through or north of the Northstar area results in estimates of about 430 and 40 bowheads that might have been disturbed by seismic operations, based on 1996 and 1994-95 data, respectively. Of these, the estimated numbers exposed to rms sound levels ≥160 dB re 1 µPa were <47 based on 1996 data and 0 based on 1994-95 data.

20 Nautical Mile Criterion.—During a meeting in Seattle on 21 May 1996, a review team requested that one of the objectives of the Northstar monitoring study be to estimate the proportion of the bowhead whales that migrate past the Northstar study site within 20 n.mi. of the northern edge of the site when the airguns are in operation. The northern edge of the exploration area was 11 km offshore, and 20 n.mi. (37 km) beyond that would be 48 km offshore. We rounded this off to 50 km to correspond to one of the 5-km distance from shore categories used in this analysis (Fig. 5.7).

We include the "20 n.mi. estimate" in this section as it is closely related to the previous "take" estimates. There is some evidence that, in summer, seismic vessels may have subtle effects on surfacing, respiration and dive cycles of bowheads at distances exceeding 20 n.mi. (37 km) (Richardson et al. 1986). Also, Inupiat whalers believe that migrating bowheads can be "displaced from their normal migratory path by as much as 30 miles" (Kanayurak et al. 1997). However, the 1996 Northstar data provide no indication that disturbance responses extended as much as 20 n.mi. (37 km) from the operating seismic vessel.

Based on 1996 data, 59 of 65 (90.8%) individuals seen were within 50 km from shore (Fig. 5.48C). Allowing for varying survey effort at different distances from shore, ~86.1% of the individual bowheads passing through the surveyed area were <50 km from shore (Fig. 5.48D). During 1994-95, 64 of 67 (95.5%) individual bowheads seen were shoreward of the

50 km line. Corrected for variable survey effort, ~92.8% of the individual bowheads migrating through the surveyed area were within 50 km of shore during 1994-95 (5.47C,D).

The factors derived earlier for proportions of bowheads passing Northstar by 18 September (**0.414**) and during times with active airguns (**0.389**) apply here as well. Therefore, we estimate that, in 1996, 13.9% of the bowhead population (0.414 × 0.389 × 0.861) passed within 20 n.mi. of the northern edge of the exploration area while the airguns were in operation. The comparable estimate based on 1994-95 data is 14.9% (0.414 × 0.389 × 0.928). Applying these proportions to the total estimated number of bowheads (8000) passing through or north of the Northstar area gives estimates of ~1100 and 1200 bowheads migrating shoreward of the 50 km line during periods of seismic operation, based on 1996 and 1994-95 data, respectively.

The percentages and numbers quoted above are presumably overestimated to a minor degree. They assume that all bowheads travel west within the area sampled by BPXA/LGL and MMS aerial surveys, which were mainly within 85 km of shore during 1996 (Fig. 5.6A). In prior years MMS has conducted more surveys of waters >85 km offshore of Northstar (Fig. 5.6B). The earlier surveys, summarized in LGL and Greeneridge (1996), show that a small proportion of bowheads occur farther north than the northernmost 1996 sighting. If 10% of the bowheads occur in those offshore waters, then the number within 20 n.mi. of the northern edge of the seismic exploration area during periods of 1996 with airgun operations may have been ~1000-1100 rather than 1100-1200.

A substantial but unknown proportion of the estimated 1000-1200 bowheads passing within 20 n.mi. of the Northstar area during times with seismic operations were exposed to seismic pulses with rms received levels below 160 dB re 1 µPa but high enough to be detectable. As discussed earlier, the number exposed to levels ≥160 dB was estimated as less than 47 bowheads. To obtain realistic estimates of the proportions of the bowhead population exposed to various other levels, e.g. 150, 140, 130 and 120 dB, it would be necessary to take account of the proportion of the time that the seismic vessel was operating in various water depths and detailed information about long-distance seaward propagation of seismic sounds in relation to source depth. By taking the available ambient noise data (Chapter 3) into account, these received level estimates could be converted to estimates of the proportion of the bowhead population exposed to seismic pulses stronger than ambient noise and presumably audible, >10 dB above ambient, >20 dB above ambient, etc. These types of analysis were beyond the scope of the present project.

Summary of Estimated "Take by Harassment".—(1) The best estimate of the number of bowheads exposed to seismic pulses at received levels ≥180 dB re 1 µPa was zero. (2) All observed bowheads were in areas where received levels of the pulses (rms measurement method) were well below 160 dB re 1 µPa. (3) Based on the distance-from-shore distributions of all bowheads seen in 1996 and earlier years, a small number of bowheads would be expected either to occur within the 160 dB radius around the seismic source vessel or to exhibit avoidance of that area. (4) Estimates of the numbers of bowheads that might occur within the 160 dB radius at some time during the late summer/autumn period are <47 bowheads (based on 1996 data) and 0 bowheads (1994-95 data), i.e. <0.6% and 0.0% of the population. (5) The small numbers expected to be "taken" in this way are likely to exhibit displacement and short-term behavioral changes, but no long-term effects on individuals or the population are expected. (6) Bowheads that would have migrated within 20 km of shore in the absence of seismic may have been displaced or otherwise disturbed during periods with seismic. If so, as many as 400 bowheads (based on 1996 data only) or 40 bowheads (considering 1994-95 data) may have been affected in these ways.

On the order of 1000-1200 bowheads may have moved west within 20 n.mi. of the northern edge of the seismic exploration area during times when airguns were operating. Many of these whales would have been exposed to seismic pulses, but this study provided no evidence that disturbance effects or "take" extended 20 n.mi. offshore of the seismic exploration area. Inupiat hunters believe that migrating bowheads can be "displaced from their normal migratory path by as much as 30 miles", and previous behavioral studies suggest that subtle behavioral effects may sometimes extend to 20+ n.mi. from seismic vessels.

All of the above estimates are imprecise given the small numbers of bowhead sightings in 1996 and in 1994-95, the two "control" years with similar ice conditions and little industrial activity, and other limitations of the data. Data from additional years with seismic exploration will be required to confirm statistically that nearshore seismic exploration has measurable effects on the autumn migration corridor of bowheads and to estimate the magnitude of any effects.

A general "Summary and Conclusions" section concerning bowheads and other cetacean species appears as §5.6 of this Chapter.

5.4 Gray Whale

The Eastern North Pacific stock of gray whales has recovered significantly over the past several decades; based on 1993-94 counts, this stock consists of about 23,100 individuals (Small and DeMaster 1995). This stock is not considered a strategic stock and it was recently (1994) removed from the List of Endangered and Threatened Wildlife. Most of these gray whales spend the summer on feeding grounds in the northern Bering and southern Chukchi seas, with significant numbers occurring northeast to Point Barrow (Clarke et al. 1989).

Gray whales are rare in the Beaufort Sea, but occasional sightings have been recorded. Maher (1960) listed records at Foggy Island, the mouth of the Shaviovik River, Flaxman Island, and Barter Island. A few single gray whales have been seen as far east as the Canadian Beaufort Sea (Rugh and Fraker 1981; W.J. Richardson, unpubl. data). These records indicate that small numbers must travel through Alaskan Beaufort waters during summer and autumn in some years. A single gray whale was reported taken by hunters at Cross Island in 1933 (Maher 1960).

A single dead gray whale was sighted by MMS on 3 September 1988 in Mikkelsen Bay near Tigvariak Island, about 60 km southeast of the eastern edge of the Northstar seismic area (Treacy 1989). No other gray whales were sighted by MMS or LGL in the Northstar region during aerial surveys conducted within the 17 year period from 1979 to 1995 (LGL and Greeneridge 1996).

During 1996, no gray whales are known to have occurred in the Northstar region. None were seen by aerial or boat-based observers during the 1996 Northstar monitoring program. None were seen during MMS's aerial surveys in the Northstar area.

The reaction thresholds of gray whales to seismic noise are similar to those of bowheads (Malme et al. 1984, 1988; Richardson et al. 1995:293*ff*). Given the historical rarity of the species in the Northstar region and the lack of sightings during 1996, it is highly unlikely that any gray whales were exposed to strong noise pulses from the 1996 Northstar seismic exploration program. Therefore, the estimated "take by harassment" during the 1996 Northstar seismic program is zero.

5.5 Beluga Whale

5.5.1 Survey Effort and Sightings, 1996

LGL and MMS Aerial Surveys, 1996.—BPXA/LGL aerial surveys were conducted on 14 days during the 1-21 September study period. Substantial coverage of the survey transects was obtained on 9 of these days (Table 5.2). On 13 days during the late summer and autumn of 1996 (1 Sep.-9 Oct.), MMS conducted transect surveys in one or more of their survey blocks 1, 2, and the eastern part of block 3 (east of 150°30'W). These areas include the Northstar region and the area where the BPXA/LGL surveys were conducted. BPXA/LGL and MMS beluga sightings during the 1 September-9 October period are mapped in Figure 5.49. A total of 88 beluga sightings and 436 individuals were recorded within the central Alaskan Beaufort Sea (146°-151°W).

Only 43 (49%) of the sightings and 152 (35%) of the individuals observed were "Transect" sightings within the Northstar area (147°-150°30'W). Most of the sightings were near or beyond the north ends of the BPXA/LGL extensive survey lines in water depths >100 m (Fig. 5.49). No belugas were seen within the Northstar seismic area in 1996. However, two groups totalling 6 whales were seen close to shore (water depth about 12 m) west of the Northstar area on 19 September, and may have passed through that area. There were only three sightings within 50 km of the seismic area (Fig. 5.49); all of those were on occasions without seismic exploration.

LGL and MMS Aerial Surveys, 1979-95.—The distributions of beluga sightings during 1996 and 1979-95 were similar (Fig. 5.49 vs. 5.50). The 1979-95 period included years with widely varying ice conditions and levels of offshore industrial activity. Therefore, the pooled 1979-95 data are not entirely comparable to those from 1996—a light-to-moderate ice year with a nearshore seismic program. However, the sightings from the 1979-95 period demonstrate that the autumn migration of the beluga through the central Alaskan Beaufort Sea consistently occurs well offshore, largely beyond the northern ends of the BPXA/LGL survey transects. Most sightings in 1979-95, like most of those in 1996, were in deep offshore waters beyond the 100 m depth contour. Even so, the offshore nature of beluga distribution is undoubtedly understated by the distributions mapped in Figures 5.50 and especially 5.48 because survey effort was limited far offshore, especially in 1996 (Fig. 5.6). Many beluga sightings in prior years were north of 71°20' (MMS survey block 10), even though aerial survey coverage there was very limited.

The only sightings in the immediate Northstar area during MMS and LGL aerial surveys from 1979 to 1995 consisted of one LGL sighting in a lagoon immediately south of Northstar during 1984 (Fig. 5.50). There were four other sightings within ~20 km of Northstar, in waters ranging from <10 to <25 m deep.

1996 Seismic vs. 1996 No Seismic.—During 1996, sightings *and* sightings per 100 km of survey effort were highest 70-80 km from shore during both seismic and non-seismic periods (Fig. 5.51). Based on these data, there is no evidence that belugas were distributed farther offshore during periods with seismic activity. However, during seismic periods there was virtually no survey effort >75 km from shore and none >80 km from shore (Fig. 5.29B). Therefore, these surveys could not have detected an offshore shift in beluga distribution if one had occurred. There were 4.8 sightings/100 km during seismic periods and 5.5 sightings/100 km during non-seismic periods. Again, the survey coverage far offshore was too limited to justify any interpretation of those values.

Overall, the combined LGL and MMS aerial survey coverage in the central Alaskan Beaufort Sea during 1996 sampled only the southern margin of the main beluga migration corridor. For this reason the data are not suitable for the detailed analyses of the types done for bowhead whales.

Timing.—In 1996, belugas were most frequently recorded in the Northstar region during the 6 to 10 September period (Fig. 5.52). However, when standardized to allow for the highly variable amounts of survey effort during different 5-d periods (Fig. 5.52E), peak sightings/100 km and individuals/100 km were recorded during the 21-25 September period.

We considered comparing the seasonal pattern of migration in 1996 with that observed in other years, e.g. 1994-95 (light ice years with nil/little offshore industrial activity). However, gaps in survey coverage during some critical 5-day time periods make this a dubious comparison (Fig. 5.44E, 5.52E).

Also, standardization by total survey effort in each 5-day period does not does not take into account varying survey effort at different distances from shore. This is an important factor for belugas, which concentrate far offshore. Years like 1996, in which BPXA/LGL surveys contributed relatively large amounts of nearshore survey effort, are not directly comparable to years like 1994, when only MMS was flying surveys. This is so even when the results are standardized for survey effort, because MMS surveys often extended farther offshore (Fig. 5.6). For this reason, and because the combined LGL and MMS 1996 surveys sampled only the southern edge of the main migration corridor, we have not attempted to

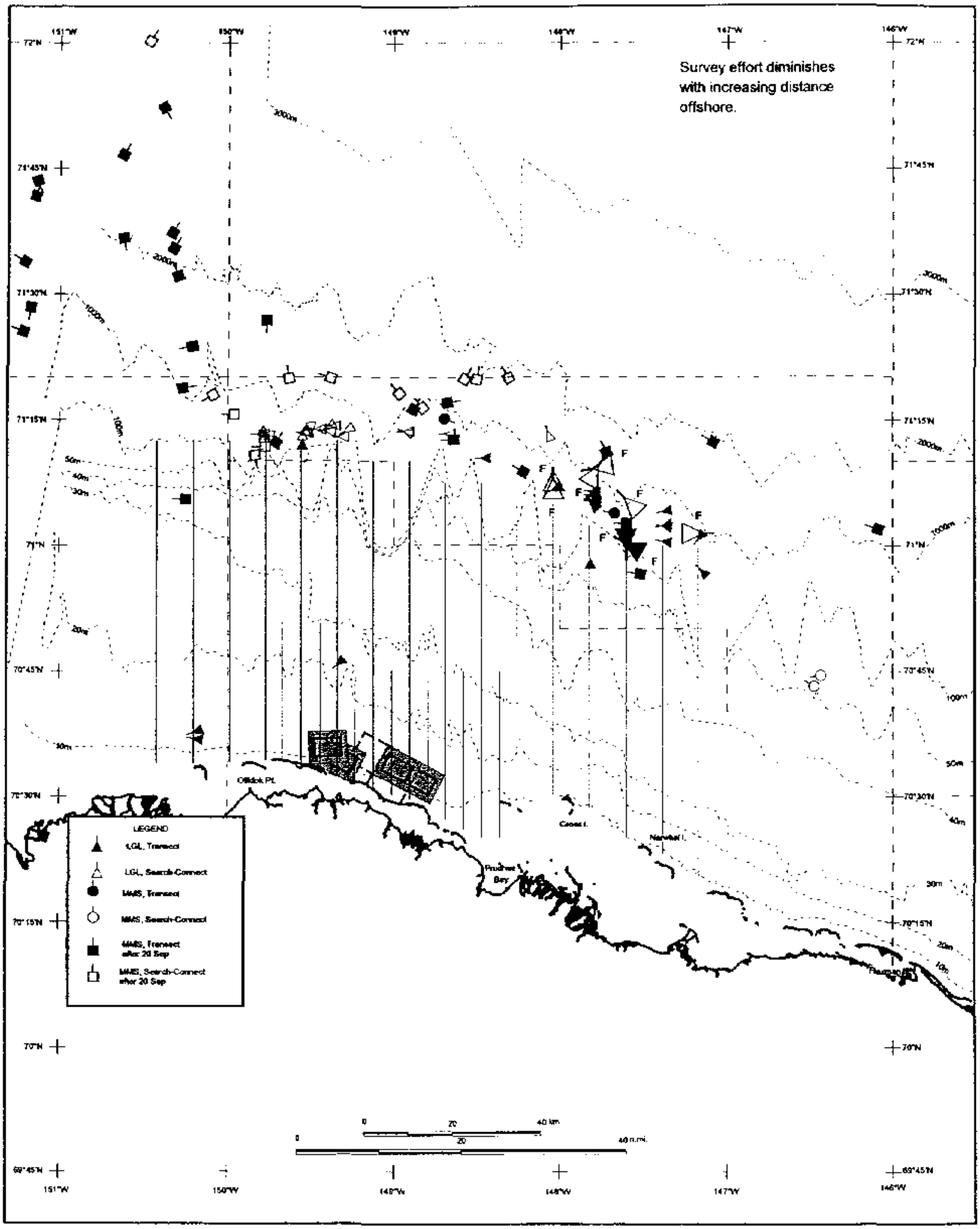


FIGURE 5.49. Beluga whale sightings in the central Alaskan Beaufort Sea (146°-151°W) during 1 September - 9 October 1996 based on LGL and MMS aerial surveys. Large symbols are sightings during "seismic" periods. Nominal LGL transect lines are shown. Dashed lines show boundaries of MMS survey blocks (*cf.* Fig.5.2). MMS sightings up to and after 20 September are distinguished. Seismic patches shot during September 1996 are outlined.

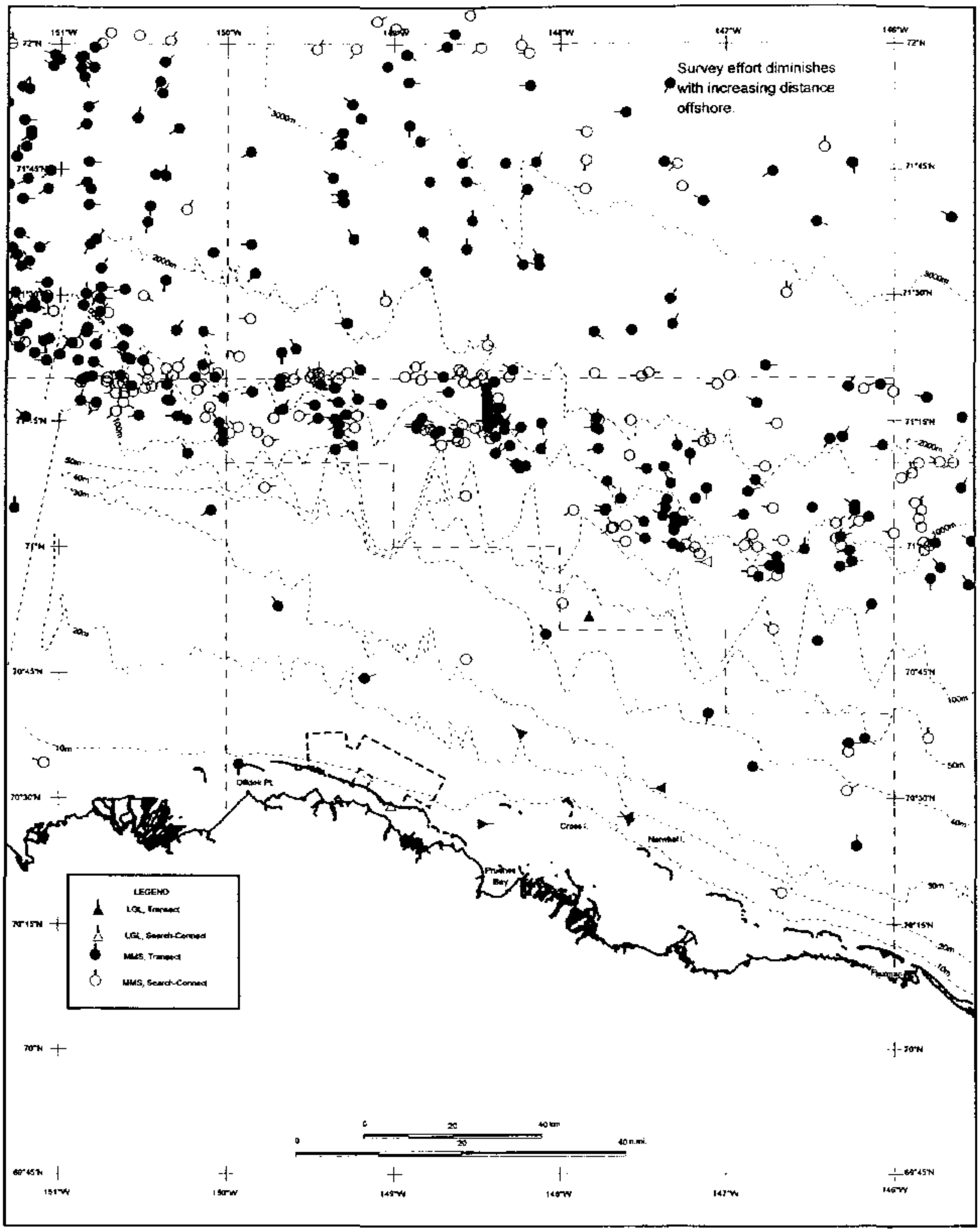


FIGURE 5.50. Beluga whale sightings in the central Alaskan Beaufort Sea (146°-151°) during late summer and autumn of 1979-95 based on MMS and LGL aerial surveys. Dashed lines show boundaries of MMS survey blocks (*cf.* Fig.5.2). Seismic patches shot during September 1996 are outlined for cross-reference.

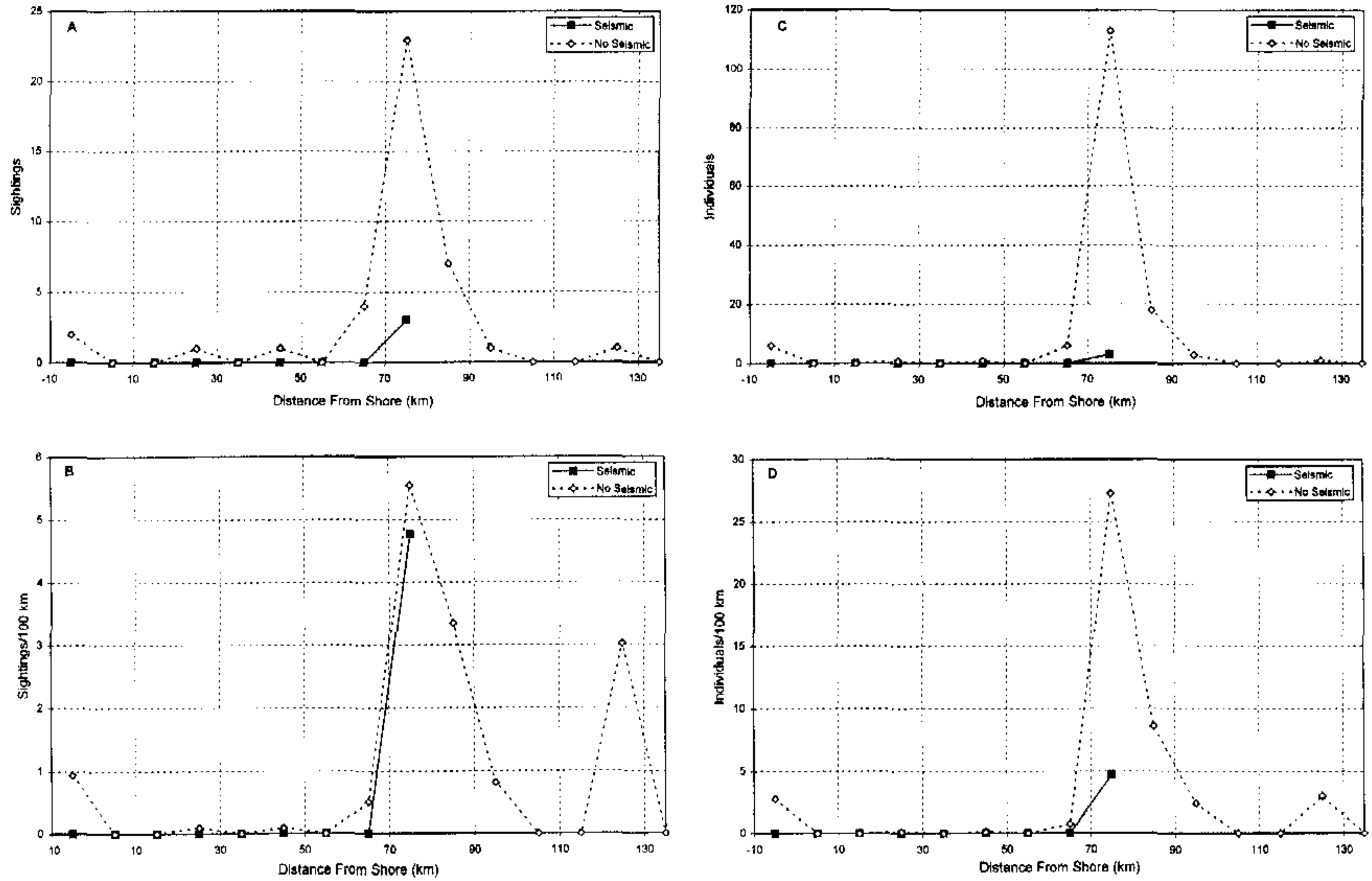
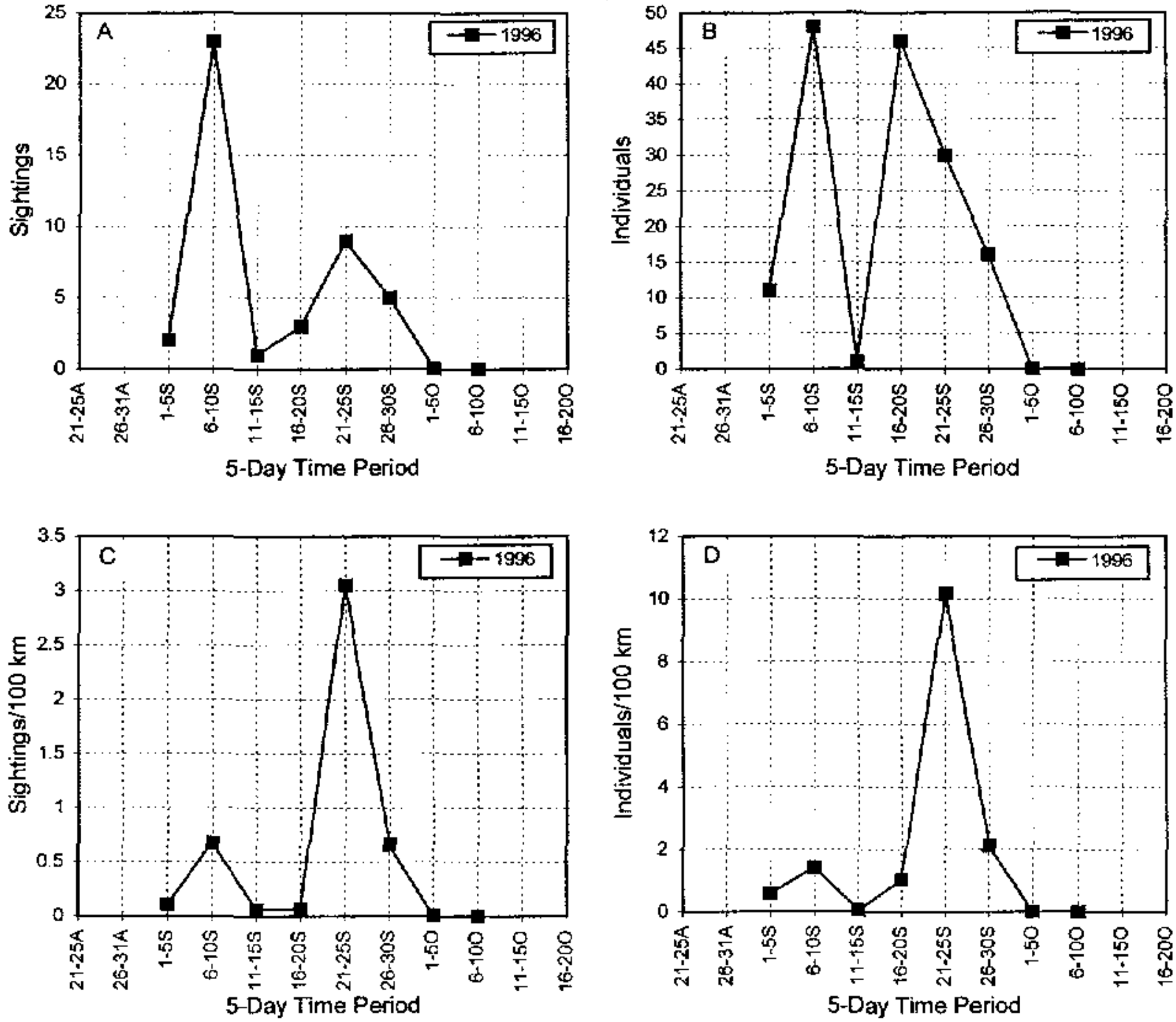


FIGURE 5.51. Distributions of belugas vs. distance from shore during "all seismic" periods vs. periods with no seismic, late summer/autumn 1996, excluding periods of poor sightability. Based on LGL and MMS "Transect" aerial surveys in the Northstar region of the central Alaskan Beaufort Sea (147°-150°30'). ***(A)*** Sightings, ***(B)*** sightings per 100 km of surveys, ***(C)*** individuals, and ***(D)*** individuals per 100 km of surveys. See Fig. 5.29 for survey effort vs. distance from shore.



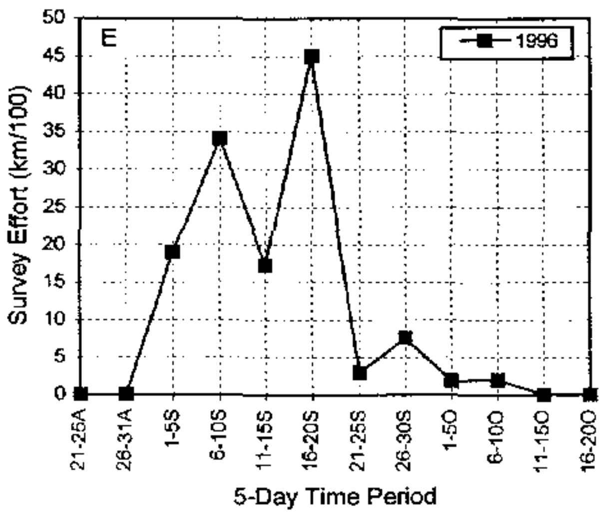


FIGURE 5.52. Seasonal pattern of belugas in 1996, including periods of poor sightability. Based on LGL and MMS "Transect" aerial surveys in the Northstar region of the central Alaskan Beaufort Sea (147°-150°30') during late summer/autumn. Includes ***(A, B)*** sightings and individuals by 5-day period, ***(C,D)*** sightings and individuals per 100 km of surveying and ***(E)*** "Transect" survey effort, in 100s of km.

compare the seasonal pattern of beluga migration observed in 1996 with the patterns observed in other years or combinations of years.

5.5.2 Estimated Beluga "Take by Harassment"

In the following analyses we have again assumed that the received rms pulse levels from the seismic source could be as high as 180 dB re 1 µPa at distances up to 1 km. They may be ≥160 dB re 1 µPa out to an average radius of 3.6 km and occasionally to a maximum of 4.9 km (Chapter 3).

180 dB Criterion.—NMFS (1995) concluded that it is unlikely that noise pulses from a nearby seismic vessel would harass odontocetes (other than sperm whales) even at a received level of 190 dB re 1 µPa. In this project, BPXA proposed a 180 dB shutdown criterion for belugas as well as bowheads, and the IHA issued by NMFS adopted that criterion for both species. The shutdown (180 dB) radius around the seismic boat was estimated in advance of the project as 650 m. On 30 August, this radius was adjusted to 750 m (except for single-gun operations), based on results of preliminary sound measurements that are now further analyzed in Chapter 3. Those analyses have shown that received levels were, at times, 180 dB re 1 µPa or more at radii as great as 1 km.

In any event, no belugas were seen within a 1 km radius of the source vessel (or anywhere nearby) at any time during either the boat-based or the aerial monitoring. At least one boat-based observer was on duty and watching for marine mammals at all hours when airgun operations were underway, for at least 30 min before all planned startups of the airguns, and at some times with no airgun operations. The boat-based observers' detection capabilities were greatly reduced at night. Even so, given the rarity of belugas in nearshore waters in this area during late summer and autumn, it is unlikely that any belugas were exposed to seismic pulses with rms received levels at or above 180 dB re 1 µPa at any time during the 1996 Northstar project.

160 dB Criterion.—The IHA indicates that, during this project, the designated zone of potential harassment for belugas is the area within which received levels of seismic pulses can exceed 160 dB re 1 µPa. The rationale for this is not identified. Insofar as we know, there are no specific data in the literature on the reaction thresholds of belugas or other small-moderate size toothed whales to seismic pulses. Beluga hearing is not very sensitive at the low frequencies where seismic sounds are strongest (Awbrey et al. 1988; Johnson et al. 1989). Nonetheless seismic sounds are strong enough to be detectable to belugas or other toothed whales at long ranges (Richardson et al. 1995:354*ff*; Richardson and Würsig in press).

No Direct Evidence of "Take": Fig. 5.49 shows that none of the beluga whales seen during the aerial surveys were within 60 km of the operating source vessel. Chapter 3 describes the transmission loss relative to the source vessel and indicates that received levels of 160 dB re 1 µPa did not normally extend beyond 3.6 km from the source vessel (maximum 4.9 km). No beluga whales seen by the aerial observers were within or near the areas where they might have been exposed to seismic pulses with received levels ≥160 dB re 1 µPa.

However, the aerial observers saw only a very small percentage of the total number of belugas that migrated west past the Northstar region during late summer and autumn in 1996. Thus, the lack of observations of belugas exposed to ≥160 dB seismic pulses does not justify an assumption that none were exposed to strong seismic pulses.

Belugas Within 15 km of Shore: The Beaufort Sea stock of the beluga whale is currently estimated to contain about **41,610 animals** (Small and DeMaster 1995). For purposes of estimating take we will assume that all of these whales migrate west north of or through the Northstar seismic exploration area. As for the bowhead, the following assessment assumes that received levels may exceed 160 dB out to a radius of 4 km. The seismic exploration area extended out to ~11 km from shore, so levels ≥160 dB could occur out to ~15 km from shore.

The Northstar seismic area is far south of the main migration corridor for the Beaufort Sea stock of beluga whales. Thus, information collected during this project on the timing and distribution of their movements is not necessarily representative of the entire beluga migration. The actual proportion of the beluga whale population that passes through the area where BPXA/LGL Northstar aerial surveys were conducted (out to about 65-85 km offshore) is unknown, but probably less than **20%**.

Based on 1996 "Transect" surveys, 3.9% (6 of 152) of the belugas that passed through the aerial survey area passed within 15 km of our "0-km line" (Fig. 5.53C). When numbers of individuals are standardized for different survey coverage in the different offshore zones, an estimated **2.1%** of the belugas passing through the aerial survey area out to 65-85 km offshore came within 15 km of the "0-km line" during 1996 (Fig. 5.53D).

The migration extends until early-to-mid-October and on the order of **60%** of the migration may occur up 18 September, when seismic work ended. As described in §5.3 Bowheads/Estimated Take, strong seismic pulses were being produced for only **38.9%** of the time during the 1-18 September period.

Summarizing the relevant factors, of the estimated 41,610 belugas in the Beaufort Sea stock, less than 20% come within the aerial survey area, about 2.1% of those passing through the aerial survey area in 1996 were within 15 km of shore, about 60% of the population migrates west through the area off Northstar during dates up to 18 September, and seismic work was underway during 38.9% of the hours from 1-18 September

If all of these percentages are applied to the stock size to estimate the maximum number of belugas that might have passed Northstar within 15 km of shore while strong seismic sounds were being emitted, the result is 41 belugas (41,610 x 0.20 × 0.021 x 0.60 × 0.389).

For reasons discussed in the bowhead section, this approach is expected to overestimate the numbers exposed to pulses with rms received levels of 160 dB re 1 µPa. It does not account for the fact that many of the estimated 41 belugas coming within 15 km of shore would be >4 km from the seismic source vessel, given that it worked within 6 km of shore 70% of the time. Thus the actual number exposed to 160 dB pulses was probably

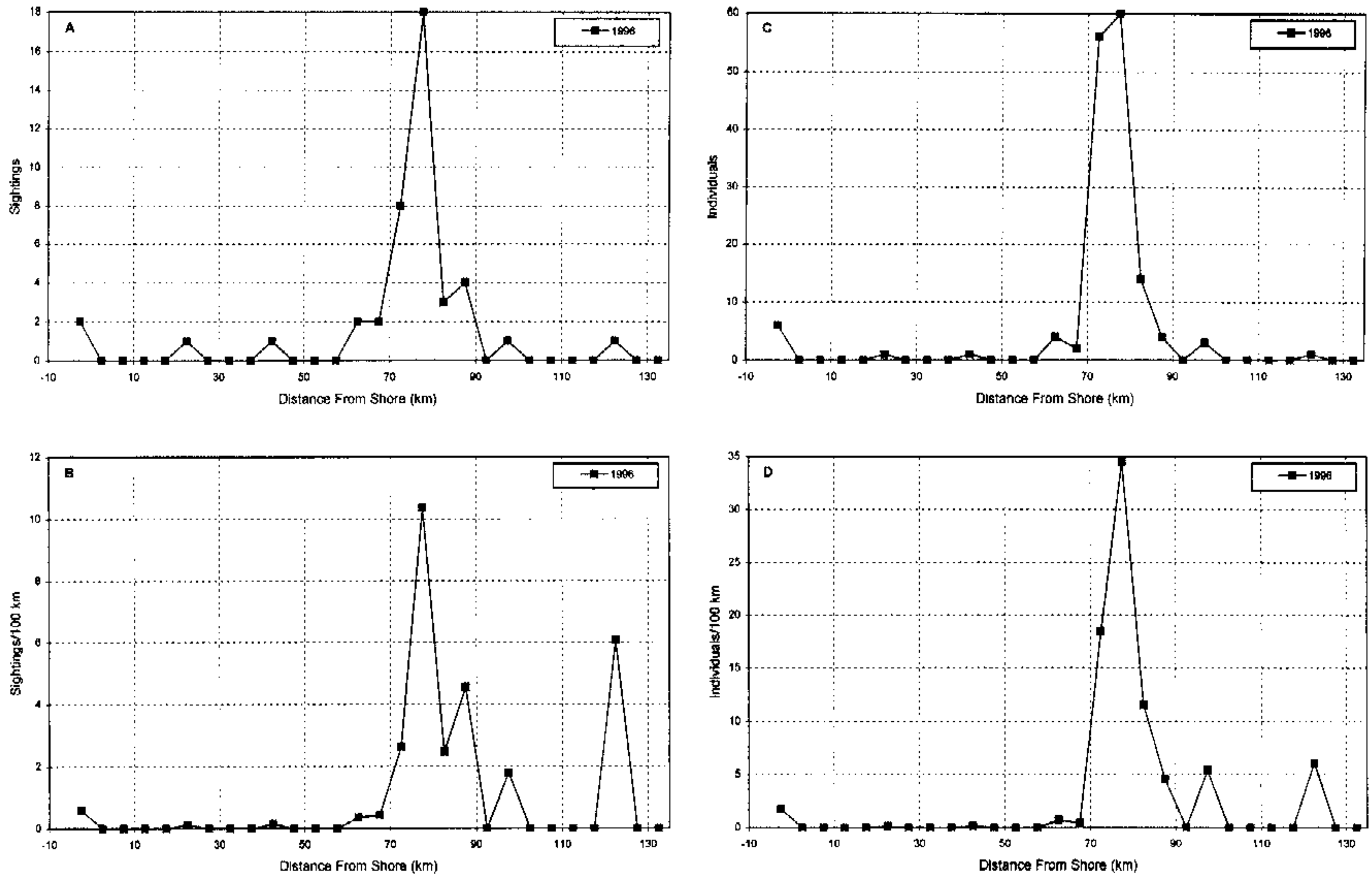


FIGURE 5.53. Distributions of belugas by 5-km distance-from-shore intervals during late summer/autumn of 1996, excluding periods of poor sightability. See Fig. 5.35B for survey effort vs. distance from shore. Otherwise as in Fig. 5.50.

considerably lower than 41, and possibly zero.

Furthermore, if 160 dB is a reasonable disturbance threshold for bowhead whales with their (presumed) sensitive low frequency hearing, it is doubtful that belugas with poor hearing sensitivity at low frequencies would be disturbed by seismic pulses at received levels of 160 dB re 1 μPa.

20 Nautical Mile Criterion.—During a meeting in Seattle on 21 May 1996, a review team requested that one of the objectives of the Northstar monitoring study be to estimate the proportion of the bowhead whales *and other marine mammals* that migrate past the Northstar study site within 20 n.mi. (37 km) of the northern edge of the site when the airguns are in operation. As described for bowheads, 20 n.mi. from the northern edge of the seismic exploration area is 48 km offshore, which we round-off to 50 km offshore. There is no evidence that belugas 20 n.mi. from a seismic vessel are disturbed or "taken by harassment".

Based on 1996 "Transect" data, 8 of 152 (5.3%) individuals that were sighted were within 50 km from shore (Fig. 5.53C). After allowing for varying amounts of survey effort at different distances from shore, an estimated 2.4% of the individual belugas occurring within the 147°-150°30'W area were inshore of the 50 km from shore line (Fig. 5.53D).

Using this **2.4%** figure together with the correction factors derived earlier for proportions of belugas passing through the BPXA/LGL survey area (**0.20**), passing Northstar by 18 September (**0.60**), and during seismic surveys (**0.389**), we estimate that **0.11%** ($0.024 \times 0.20 \times 0.60 \times 0.389$) of the beluga population passed within 20 n.mi. of the northern edge of Northstar in 1996. By applying this proportion to the total estimated number of belugas (41,610) passing through or north of the Northstar area, we estimate that roughly 47 belugas traveled west shoreward of the 50 km from shore line in 1996, i.e. within about 20 n.mi. of the northern edge of Northstar.

Summary of Estimated "Take by Harassment".—It is very unlikely that any belugas were exposed to seismic pulses with rms received levels ≥180 dB re 1 μPa during the 1996 Northstar seismic program. No belugas were directly observed to be exposed to pulses with received levels of ≥160 dB either. Even allowing for belugas migrating past the seismic operation at times when they could not be observed, only a very low proportion of the Beaufort Sea stock, probably well under 41 animals, might have exposed to seismic pulses with received levels ≥160 dB re 1 μPa on a rms basis. If these animals were disturbed by hearing the seismic sounds, the effect was likely short term and localized, with no lasting consequences for individuals or the population. The disturbance threshold may be above 160 dB, in which case the number potentially "taken by disturbance" would be predicted to be even lower.

5.6 Summary and Conclusions

No cetaceans were seen in the Northstar study area by the boat-based marine mammal observers. During July through September 1996, the observers watched for marine mammals at all times while airgun operations were in progress, for at least 30 min before all planned startups of the airguns, and at some times with no airgun operations

Partial or complete BPXA/LGL aerial surveys were flown on 14 dates from 3 to 20 September 1996, including 6648.3 km of survey coverage during periods with no seismic and 3576.2 km during periods potentially influenced by seismic activities: 791.3 km during partial array seismic (all of it with five airguns), 2259.4 km during full array seismic, and 525.5 km during post-seismic periods (i.e. 0-3.5 hours after the end of full array seismic).

The Minerals Management Service conducted transect surveys in the same area on 13 days in 1996. Only 2% of the transect surveys flown by MMS in the Northstar area were during seismic periods (51 of 2747 km with 5-gun "partial array" or "post-seismic").

5.6.1 Bowhead Whale

During the BPXA/LGL aerial surveys, there were 58 sightings of bowheads involving 77 individuals. Of these,

- 7 sightings and 7 individuals were with full array seismic,
- 2 sightings and 2 individuals were with partial array seismic (and within 3.5 h after the end of full-array seismic),
- 8 sightings and 12 individuals were during post-seismic periods, and
- 41 sightings and 56 individuals were during no-seismic periods.

There was no immediately obvious relationship between the numbers of bowheads sighted and the status of the seismic array during the aerial surveys. Relatively large numbers of bowheads were seen during some days with seismic and some days without seismic. Likewise, few bowheads were recorded on other days with seismic and without seismic. Overall, we saw an average of 0.59 bowheads per 100 km of surveys during all seismic conditions combined (n=17 sightings and 21 individuals), and 0.84 bowheads per 100 km of surveys without seismic (n=41 and 56). The closest sightings of bowheads with respect to the operating airgun array were 22-27 km away.

MMS obtained 29 sightings of 39 individual bowheads in this area. Twelve MMS sightings including 17 individual bowheads were recorded up to 18 September when seismic exploration ended. None of these sightings were during seismic periods.

Distance from Shore.—The number of bowhead sightings within the Northstar region during LGL and MMS aerial surveys in 1996 was small, and only a minority of these sightings were during (n=9) or within 3.5 h after (n=8) periods of seismic exploration. It is not appropriate to draw general conclusions about effects of seismic exploration on the position of the bowhead migration corridor based on this 1996 monitoring study alone. However, the following points were evident from the data available:

1996 Seismic vs. 1996 No Seismic: Bowheads tended to be seen both closer to shore and farther offshore without seismic than with seismic. The modal distance from shore was ~10 km farther offshore with seismic, consistent with the possibility of seaward displacement by seismic, when data collected under poor sightability conditions were included. However, the distributions with and without seismic overlapped broadly, and when poor sightability data were excluded sightings tended to be *closer* to shore with seismic than without seismic.

1996 East vs. 1996 West: There was no evidence that distances from shore were greater in the western than in the eastern part of the Northstar region.

1996 vs. 1994-95: We found no evidence that bowheads were distributed farther from shore in 1996 (either overall or during times with seismic) than in 1994-95 (years with little or no offshore industrial activity). If anything, bowhead migration tended to be closer to shore during 1996, the year with seismic.

Years with Little vs. Substantial Industrial Activity: Bowhead sightings tended to be slightly farther offshore during 1996 plus four other light ice years with substantial industrial activity than during two light ice years without activity. This difference was statistically significant ($P<0.05$).

Available data are insufficient to determine whether the tendency for the southern edge of the main bowhead migration corridor to be farther offshore with seismic or other industrial activities is indicative of a causal relationship. The tendency was not statistically significant for seismic but was significant considering the larger sample of data for industrial activities in general. The observed tendencies are consistent with the experience of bowhead hunters.

Most bowheads seen with seismic exploration were within ~20-30 km from shore, and thus apparently passed within ~10-20 km of the northern edge of the seismic area. There was much overlap between the migration corridors in years with vs. without seismic or other industrial activities.

Data from additional years with seismic exploration will be required to confirm statistically that nearshore seismic exploration has measurable effects on the autumn migration corridor of bowheads and to estimate the magnitude of any effects.

Behavior, Headings and Migration Timing.—Based on small sample sizes, there was no indication that resting at the surface was appreciably more common during seismic than no-seismic periods.

The headings of bowheads engaged in "swimming" were bimodal both with and without seismic exploration during 1996. The percentage of bowheads heading in unexpected directions in the Northstar region during 1996 was not significantly different from that in 1994-

95, when there were no offshore industrial activities. Headings during five years with substantial offshore industrial activity did not differ significantly from those during 1994-95. However, based on a very small sample, bowhead headings in eastern and western portions of the study area differed significantly, with more bowheads heading in "other" directions in the western portion (i.e. near Northstar).

Bowhead numbers in the Northstar region, averaged by 5-day periods, seemed fairly steady during the 1-30 September period of 1996. On average, peak sighting rates occurred ~10 days later during during five light ice years with substantial industrial activity than during two light ice years with little industrial activity (1994-95). However, the 1994-95 data were limited, and no conclusions can be drawn about industry effects on migration timing.

Bowhead Call Counts.—Bottom-mounted acoustic recorders operated simultaneously at sites offshore from Northstar and from Narwhal Island (45 km ESE of the Northstar recorder) from 31 August to 14 September 1996. The recorders were near the 25 and 30 m depth contours, respectively, in the zone defined as being 20-25 km from shore. They recorded 6920 and 17,634 bowhead calls, respectively, during 351 h of simultaneous operations.

The number of calls detectable per hour near Northstar was significantly lower, both overall and relative to the paired Narwhal Island count, during hours when seismic pulses were detectable on the Northstar recorder. Ensonification of waters near Northstar by seismic sounds apparently had one or both of the following effects: it reduced the number of calls emitted by an average bowhead per hour, and/or reduced the number of bowheads within a several kilometer distance of the recording unit off Northstar.

Sounds Received Near Bowheads.—The strongest seismic pulses measured near bowheads observed during this project had peak levels near 122 dB and rms levels near 114 dB re 1 µPa. However, we probably did not record the strongest sounds received by the bowheads that were sighted during this project. Whales traveling west 15 km offshore could have been exposed to rms pulse levels approaching (but not exceeding) 160 dB re 1 µPa if they passed when the airgun array was operating near the northern edge of the seismic operations area (10-11 km offshore). Whales traveling west <15 km offshore, as some did in the absence of seismic, could have been exposed to levels ≥160 dB if they animals did not deflect away from the seismic vessel.

Estimated "Take by Harassment".—The best estimate of the number of bowheads exposed to seismic pulses at received levels ≥180 dB re 1 µPa was zero. All observed bowheads were in areas where received levels of the pulses (rms measurement method) were well below 160 dB re 1 µPa.

Based on the distance-from-shore distributions of all bowheads seen in 1996 and selected earlier years, a small number of bowheads would be expected either to occur within the 160 dB radius around the seismic source vessel or to exhibit avoidance of that area. Estimates of the numbers of bowheads that might occur within the 160 dB radius at some time during the late summer/autumn period are <47 bowheads (based on 1996 data) and 0 bowheads (1994-95 data), i.e. <0.6% and 0.0% of the population. The small numbers expected to be "taken" in this way are likely to exhibit displacement and short-term behavioral changes, but no long-term effects on individuals or the population are expected.

Bowheads that would have migrated within 20 km of shore in the absence of seismic may have been displaced or otherwise disturbed during periods with seismic. If so, as many as 430 bowheads (based on 1996 data only) or 40 bowheads (considering 1994-95 data) may have been affected in these ways.

On the order of 1000-1200 bowheads may have moved west within 20 n.mi. (37 km) of the northern edge of the seismic exploration area during times when airguns were operating in 1996. Many of these whales would have been exposed to seismic pulses. This study provided no evidence that disturbance effects or "take" extended 20 n.mi. offshore of the seismic exploration area. Inupiat hunters believe that migrating bowheads can be "displaced from their normal migratory path by as much as 30 miles", and previous behavioral studies suggest that subtle behavioral effects may sometimes extend to 20+ n.mi. from seismic vessels.

5.6.2 Gray and Beluga Whales

Gray whales are rare in the Northstar region, and none were sighted during BPXA/LGL or MMS surveys in 1996. For gray whales, the estimated "take by harassment" during the 1996 Northstar seismic program was zero.

Beluga migration during 1996 was predominantly far offshore, as in other years. Almost all sightings during 1996 were at the extreme northern edge of the study area. However, as usual, a few small groups traveled west through nearshore waters.

The combined LGL and MMS aerial surveys during 1996 sampled only the southern margin of the main beluga migration corridor. For this reason the data are not suitable for the detailed analyses of distances offshore with and without seismic, in various years, etc.

Roughly 47 belugas were estimated to have traveled west within about 20 n.mi. (37 km) of the northern edge of the seismic exploration area during periods with seismic work.

The number of belugas "taken by harassment" was small and perhaps zero. It is very unlikely that any belugas were exposed to rms received levels ≥180 dB re 1 μPa. No belugas were directly observed to be exposed to rms received levels ≥160 dB. Allowing for belugas migrating past the seismic operation at times when they could not be observed, a very low proportion of the Beaufort Sea stock, probably under 41 animals, might have been exposed to ≥160 dB. The disturbance threshold may be above 160 dB, in which case the number potentially "taken by disturbance" would be predicted to be even lower.

5.6.3 Summary Organized by Objectives

Eight analysis objectives were identified at a meeting held in Seattle on 21 May 1996 to review the draft monitoring plan (see §1.2 in Chapter 1). All of these objectives dealt with whales either in whole or in part:

(a) "Estimate the proportion of the bowhead whales (and other marine mammals) that migrate past the Northstar study site within 20 nm of the northern edge of the site when the air guns are in operation."

> On the order of 1000-1200 bowheads may have moved west within 20 n.mi. (37 km) of the northern edge of the seismic exploration area during times when airguns were operating in 1996. Many of these whales would have been exposed to seismic pulses. [Based on §5.3.8, page 5-93*ff*].

(b) "Estimate the number of other marine mammals within 20 nm of the northern edge of the study site when the air guns are in operation."

> An estimated 47 belugas traveled west within about 20 n.mi. of the northern edge of the seismic exploration area during times when airguns were operating in 1996. [Based on §5.5, page 5-105].

(c) "Estimate the number of baleen whales within 2130 ft of the sound source when the air guns are in operation."

> The radius within which the rms level of the seismic pulses was expected to be ≥180 dB re 1 μPa was initially estimated as 650 m (2130 ft). The 180 dB radius was later determined to be up to 1.0 km on some occasions (Chapter 3). The best estimate of the number of bowheads exposed to seismic pulses at received levels ≥180 dB re 1 μPa was zero. [Based on §5.3.8, page 5-87]. No gray whales were seen during this study, and presumably none were exposed to a received level ≥180 dB re 1 μPa.

(d) "Estimate the number of other marine mammals within 500 ft of the sound source during seismic operations."

> No belugas were seen or suspected to occur within 500 ft (150 m) of the sound source. [Based on §5.5, page 5-102]. Results for seals are given in Chapter 4.

(e) "Estimate the distribution of observed distances between the (closest) active seismic vessel and bowhead whales seen on effort during the aerial survey."

> The distances of observed bowheads from the active or recently-active seismic vessel are listed in Table 5.3 in §5.3.1; the distances ranged from 21 to 74 km. However, most of these whales were probably not at their closest points of approach when seen. Figure

5.47 (page 5-86) shows the location of the whale migration corridor in 1996 relative to the outer (northern) edge of the seismic exploration area.

(f) "Test the hypothesis that the distribution of bowhead whales (and other marine mammals) is independent of the estimated received sound level produced by all of the vessels associated with the Northstar study."

The southern edge of the main bowhead migration corridor tended to be farther offshore at times with seismic than at times without seismic during 1996. The 1996 data were insufficient to determine statistically whether this trend was indicative of a causal relationship, given the small sample size available from a single year of surveys (see §5.3.3, page 5-52*ff*]. However, the observed tendency was consistent with the experience of bowhead hunters.

(g) "Test the hypothesis that the swimming direction of bowhead whales is independent of the estimated received sound level produced by all vessels associated with the Northstar study."

The headings of bowheads engaged in "swimming" were bimodal both with and without seismic exploration during 1996. The percentage of bowheads heading in unexpected directions during 1996 was not significantly different from that in 1994-95, when there were no offshore industrial activities. However, based on a very small sample, more bowheads headed in unexpected directions in the western part of the study area (near Northstar) than in the eastern part (farther away). [Based on §5.3.4, page 5-71*ff*].

(h) "Test the hypothesis that vocalization rates of bowhead whales are independent of the estimated received sound level produced by all vessels associated with the Northstar study (using some type of remote data collection system)."

The number of calls detectable per hour near Northstar was significantly lower, both overall and relative to the paired Narwhal Island count, during hours when seismic pulses were detectable on the Northstar recorder. Ensonification of waters near Northstar by seismic sounds apparently had one or both of the following effects: it reduced the number of calls emitted by an average bowhead per hour and/or reduced the number of bowheads within a several kilometer distance of the recording unit off Northstar. [Based on §5.3.6 (page 5-81*ff*) and §3.8 in Chapter 3].

5.7 Acknowledgements

The aerial surveys were conducted as authorized by an Incidental Harassment Authorization issued by the U.S. National Marine Fisheries Service to BP Exploration (Alaska) Inc. for BPXA's Northstar seismic program. The monitoring work was funded by BPXA via a contract to LGL and Greeneridge Sciences. We thank Dr. Chris Herlugson of BPXA for support and assistance throughout the project. We also thank Michelle Gilders for assistance during the early stages and for reviewing the draft report.

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Tom Cook and Joe King kindly provided information on the locations and activities of the whalers, which permitted us to obtain maximum information on whale distribution without interfering with the whale hunt.

We are grateful to the marine mammal monitoring crew aboard the seismic source vessel, the *Point Barrow*, for their long hours of effort in watching for cetaceans as well as seals. We also appreciate the assistance that many other individuals and organizations provided to the boat-based observers. Full acknowledgements concerning the boat-based work are given in Chapter 4, SEALS.

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APPENDIX 1:

SIGHTINGS OF WALRUSES AND POLAR BEARS

BP Exploration (Alaska) Inc. (BPXA) conducted an open-water seismic program in shallow waters of the central Alaskan Beaufort Sea during the 24 July through 19 September period of 1996. Incidental (unintentional) takes of polar bears and Pacific walruses during BPXA's exploration activities were authorized by a letter dated 15 May 1996 from the U.S. Fish & Wildlife Service (USFWS) under Section 101(a)(5) of the Marine Mammal Protection Act. One requirement of this authorization was that all sightings and/or interactions with polar bears and walruses be reported to the Marine Mammal Management Office. The following writeup is extracted from a brief report by LGL Ltd. for BPXA and USFWS, dated January 1997. That report summarized all polar bear and walrus sightings during BPXA's 1996 open water seismic exploration program and its associated marine mammal monitoring program.

Additional background information, including a detailed description of the seismic program and of the marine mammal monitoring methods, can be found earlier in the present report. The marine mammal monitoring work described there was designed to satisfy the requirements of the Incidental Harassment Authorization (IHA) issued by NMFS to BPXA. The IHA authorized incidental disturbance to whales and seals, and required a comprehensive boat-based, aerial and acoustic monitoring program to document the "take" of these mammals. Corresponding information about polar bears and walruses was also collected during the monitoring program.

Walrus

Two Pacific walruses were sighted during the 1996 Northstar open-water seismic program (Table 1). One sub-adult walrus was sighted by marine mammal monitors aboard the seismic source vessel *Pt. Barrow* on 6 August 1996. The *Pt. Barrow* was transiting between seismic lines when the walrus was first sighted. The walrus followed the vessel for about 50 minutes and was at one time within about 50 m of the *Pt. Barrow*. The *Point Barrow* eventually out-distanced the walrus by increasing its speed. The walrus was almost out of sight (≥400 m behind the vessel) when the vessel reached the start of its line and began firing a single airgun.

A single adult walrus was observed on 10 September 1996 from the survey aircraft used for marine mammal monitoring (Table 1). This walrus was located about 36 km from the source vessel, which was operating the full airgun array at the time of the sighting (Fig. 1). The walrus responded to the aircraft by turning in the water to look at the aircraft. The aircraft passed at a lateral distance of about 200 m from the walrus at an altitude of 280 m above sea level. The walrus did not dive during the brief period that it remained in sight.

Table 1. Sightings of Pacific walrus and polar bears during the 1996 Northstar open-water seismic program.

Species	Observation Platform		Da/Mo/Yr	Local Time	Lat.	Long.	Behavior/ Reaction	Number			Percent Ice cover
	Type	Name						Total	Ad.	Sub-ad.	
P. Walrus	Vessel	Pt. Barrow	06/08/96	093900	70 20.5	147 37.7	Follow vessel	1		1	0
"	Aircraft	N7UP	10/09/96	102412	70 51.3	149 19.9	Look at aircraft	1		1	6-25
Polar Bear	Aircraft	N7UP	05/09/96	124354	70 41.8	148 27.9	Resting/sitting/standing	2			6-25
"	"	"	07/09/96	105500	70 54.3	147 22.9	Resting/sitting/standing	2	1	1	76-90
"	Vessel	Sag River	10/09/96	171900	70 36.5	149 11.3	Swim away from vessel	2	2		+
"	"	Peregrine	"	202500	70 34.9	149 10.1	Climbing on ice	2	1	1	+
"	Aircraft	N7UP	19/09/96	123610	70 47.7	149 20.4	Resting/sitting/standing	3	1	2	76-90
"	"	"	"	125158	70 40.8	149 06.9	Feeding	1			91-99
"	"	"	"	142830	70 43.7	149 39.7	Unknown	1			26-50
"	"	"	"	172255	70 52.9	147 48.9	Travel	1			91-99
"	"	"	"	180525	70 53.1	147 22.6	Resting/sitting/standing	1			51-75
"	"	"	20/09/96	112616	70 49.7	148 54.1	Resting/sitting/standing	2			91-99
Ringed Seal*	Vessel	Pt. Barrow	17/09/96	094700	70 36.8	149 17.7	Dead on ice	1	1		+

* Killed by polar bear

Polar Bear

There were two vessel-based sightings of polar bears on 10 September 1996 (Table 1). Two polar bears, reported to be adults, were sighted by the crew of the *Sag River* at 17:19 local time. The bears were estimated to be about 300 m from the vessel. The vessel came to a stop and the bears were observed both on ice and swimming away from the vessel. The encounter lasted about 10 minutes. At the time of the sighting the source vessel *Pt. Barrow* was about 10 km to the ESE. The source vessel had been shooting full-array seismic throughout the day, and the array was being ramped-up in preparation for starting a new line when the bears were first sighted.

The second sighting on 10 September was also of two bears, reported to be a sow and a cub, at 20:25. This sighting, by the crew of the *Peregrine,* was about 3 km south of the *Sag River's* earlier sighting. This pair was observed climbing onto a large ice pan as the *Peregrine* picked up buoys on either side of the ice pan. The bears were estimated to be about 200 m from the vessel and the encounter lasted about 10 minutes. At the time of this sighting the source vessel *Pt. Barrow* was shooting full-array seismic about 4 km SE of the bears.

Eight sightings of including a total of 13 polar bears were recorded by the biologists on board the survey aircraft used for marine mammal monitoring (Table 1, Fig. 1). No seismic shooting occurred in the Northstar area on the days (5, 7, 19, 20 September) when these polar bears were sighted. No reactions to the aircraft were observed.

A dead ringed seal, believed to have been killed by a polar bear, was observed on an ice pan by marine mammal monitors on board the source vessel *Pt. Barrow* on 17 September. This seal was about 6 km west of the area where bears had been sighted on 10 September.

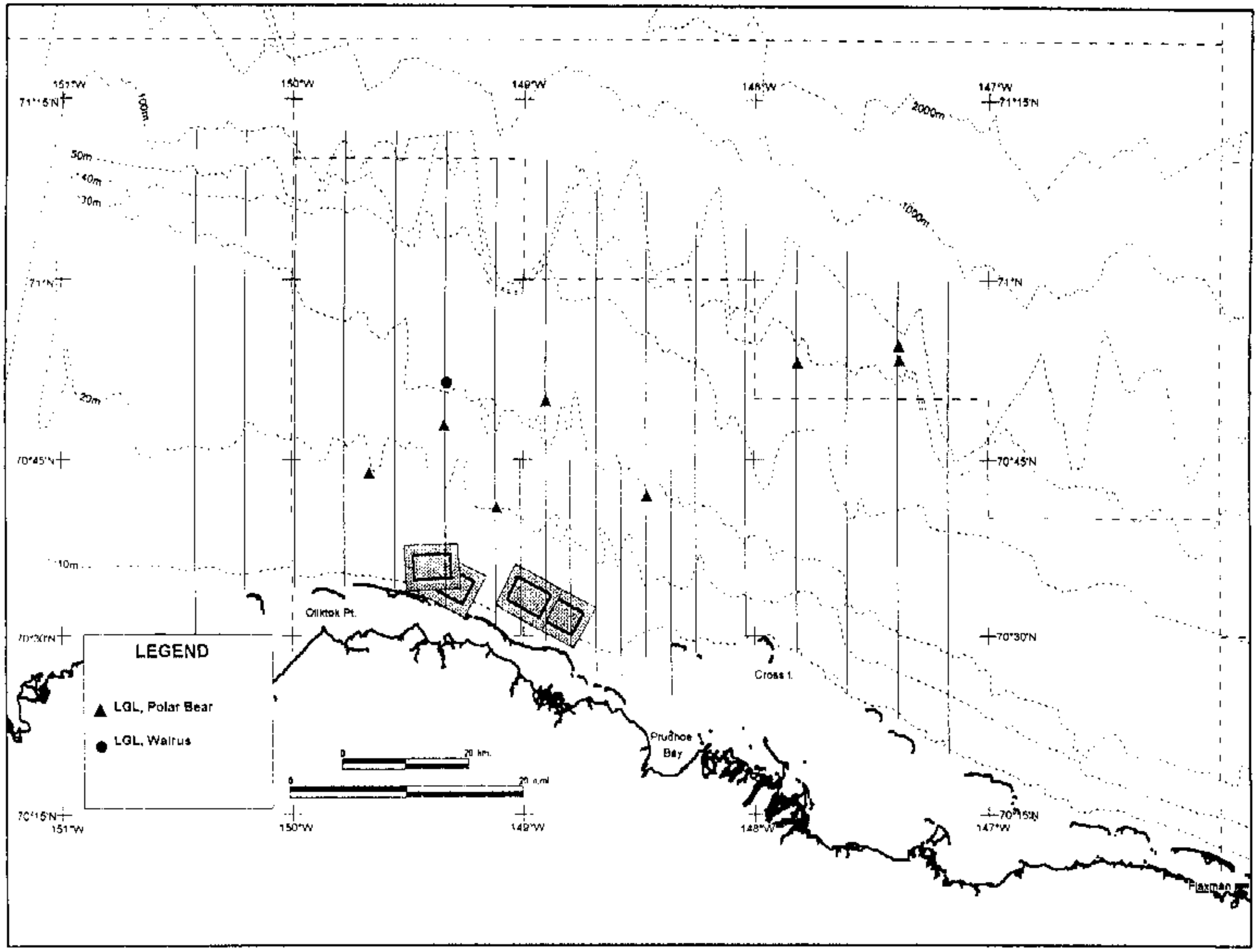

FIGURE 1. Sightings of polar bears (triangles) and walrus (circle) during aerial surveys conducted as part of the Northstar marine mammal monitoring program, 1-21 September 1996. Aerial surveys of a standard grid (shown) were conducted daily, weather permitting. A total of 10,225 km of surveys were conducted on 14 dates; not all lines were surveyed on each date. See Chapter 5 for a description of the aerial surveys. Shaded rectangles show the areas where the source vessel shot full-array and partial-array seismic during the dates when aerial surveys were done.