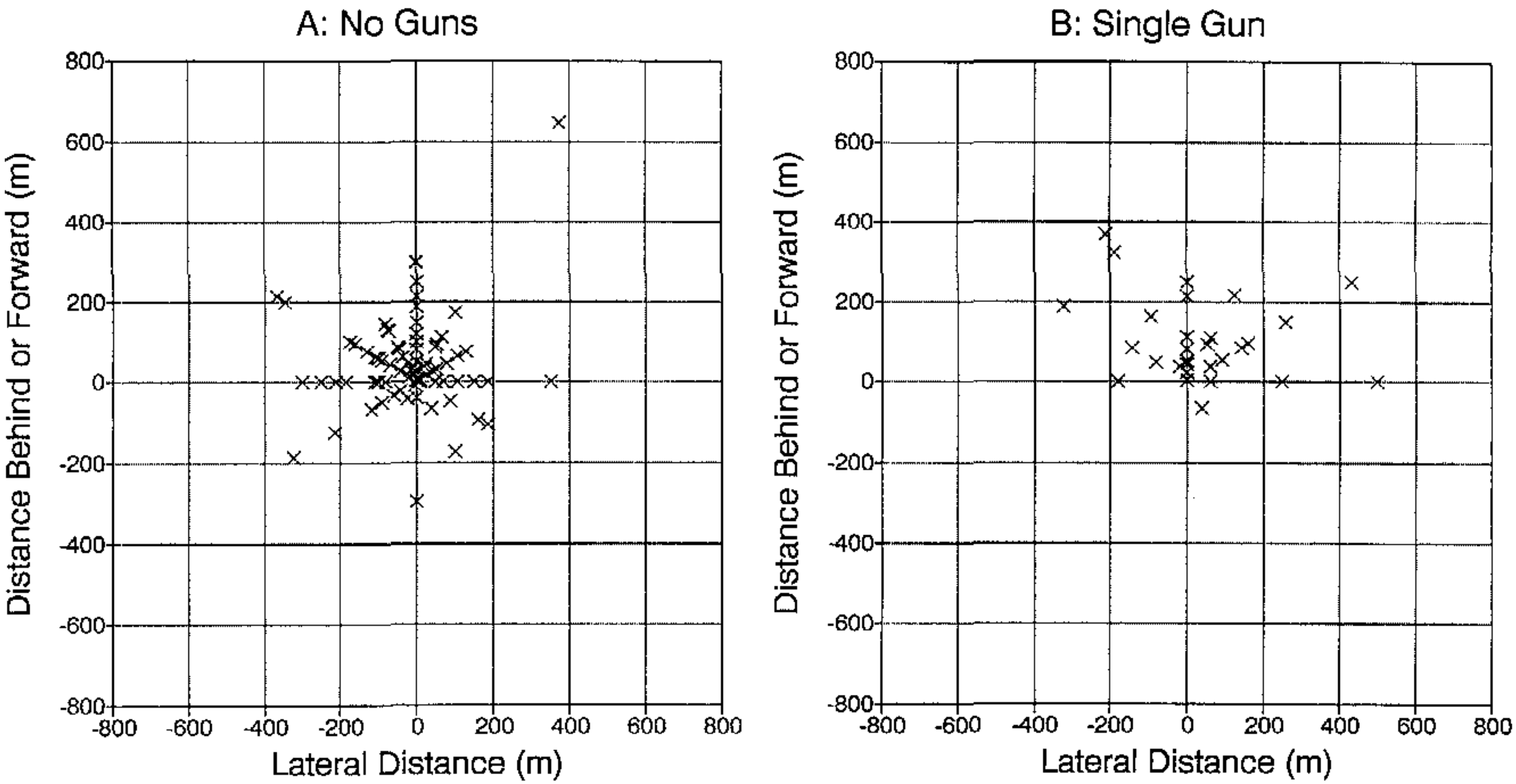

FIGURE 4.7. Distribution of the initial sightings of seals around the source vessel under different seismic conditions, and for all sightings. The seismic vessel is located at coordinates 0-0.

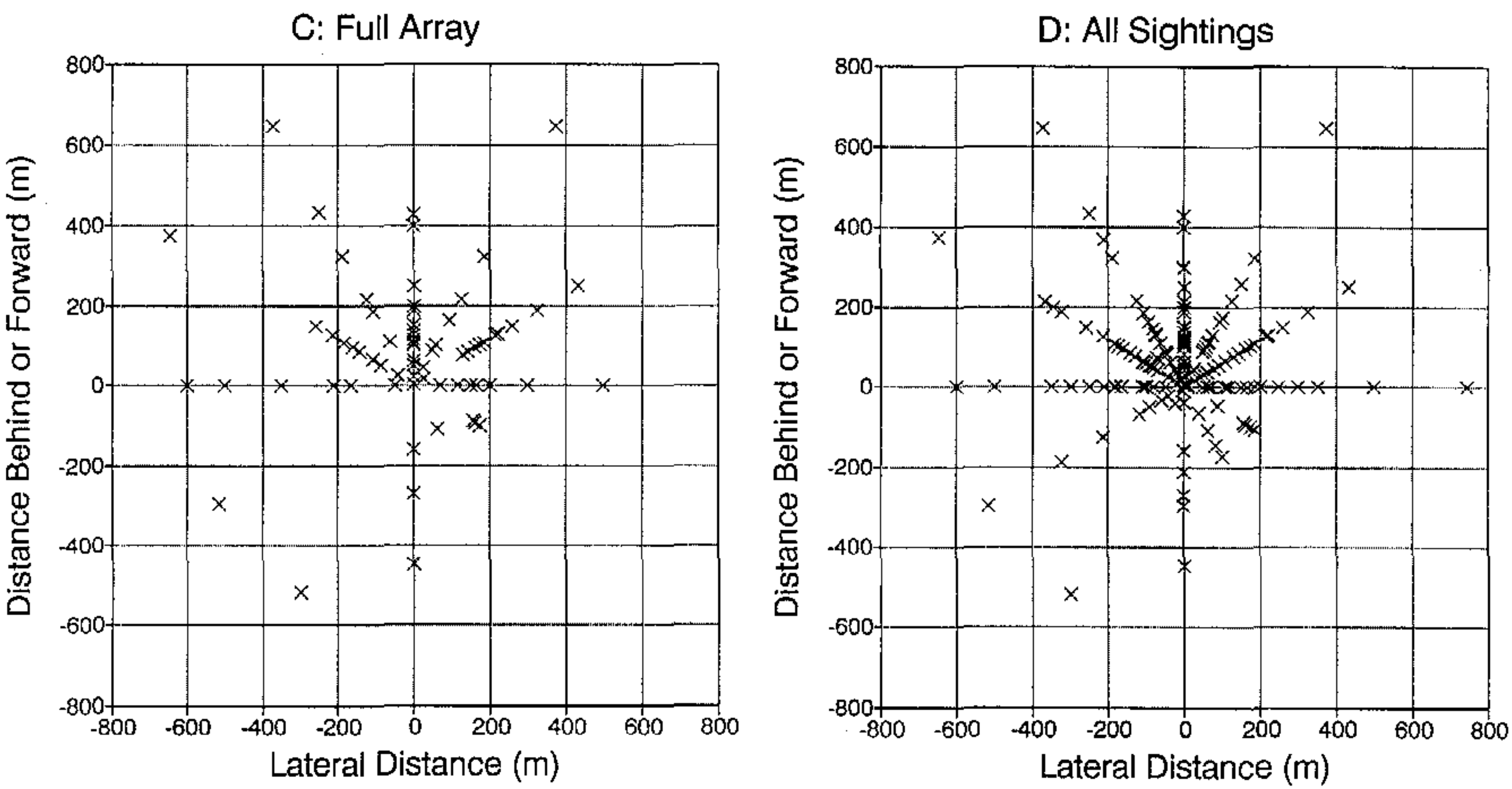

FIGURE 4.7. Continued.

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-

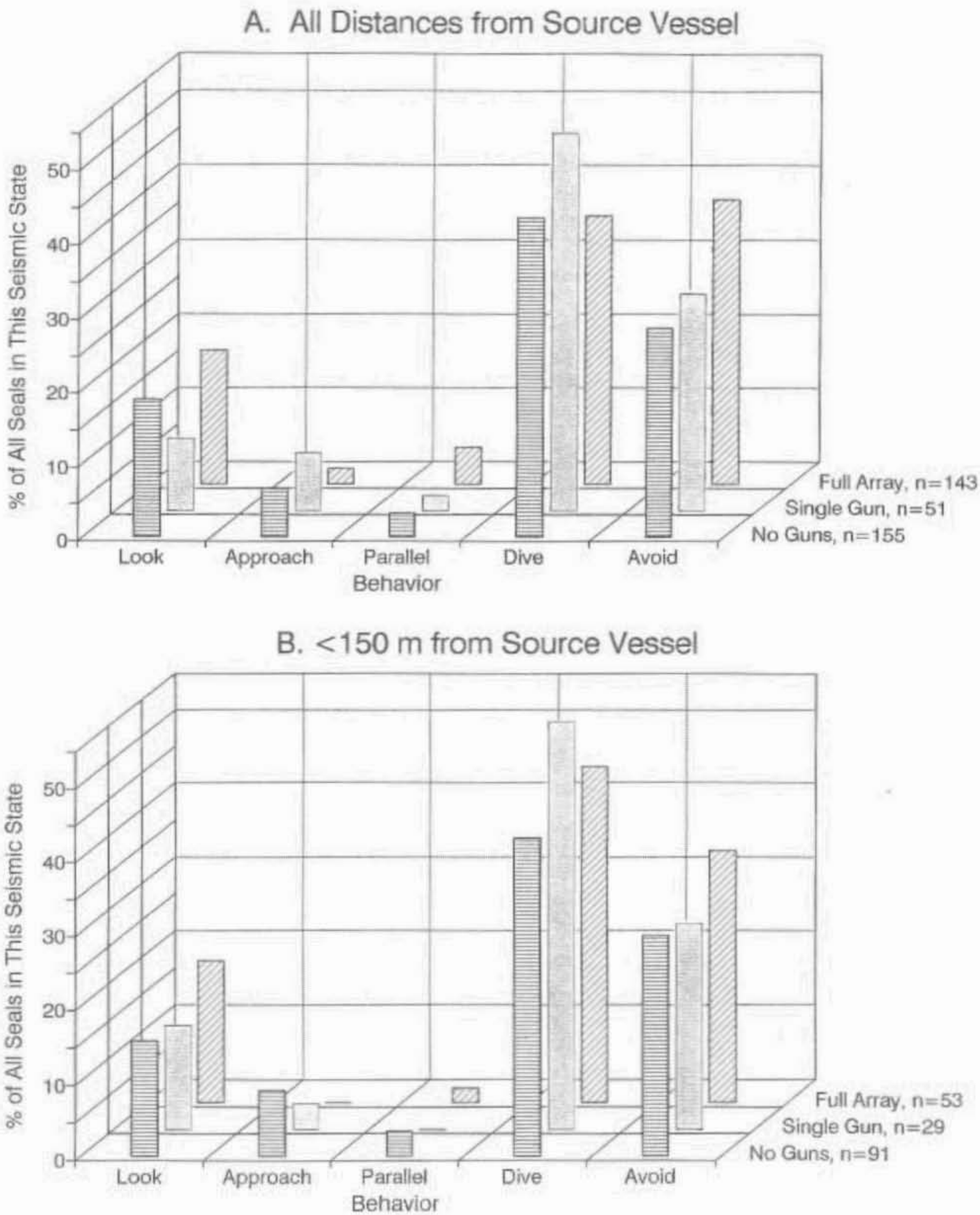

FIGURE 4.8. Observed behaviors of seals during different seismic states and at different distances from the source vessel. For each seismic state, the bars show the percentages of the seals that exhibited various behaviors. Table 4.5 shows corresponding numerical details and the few data from "partial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

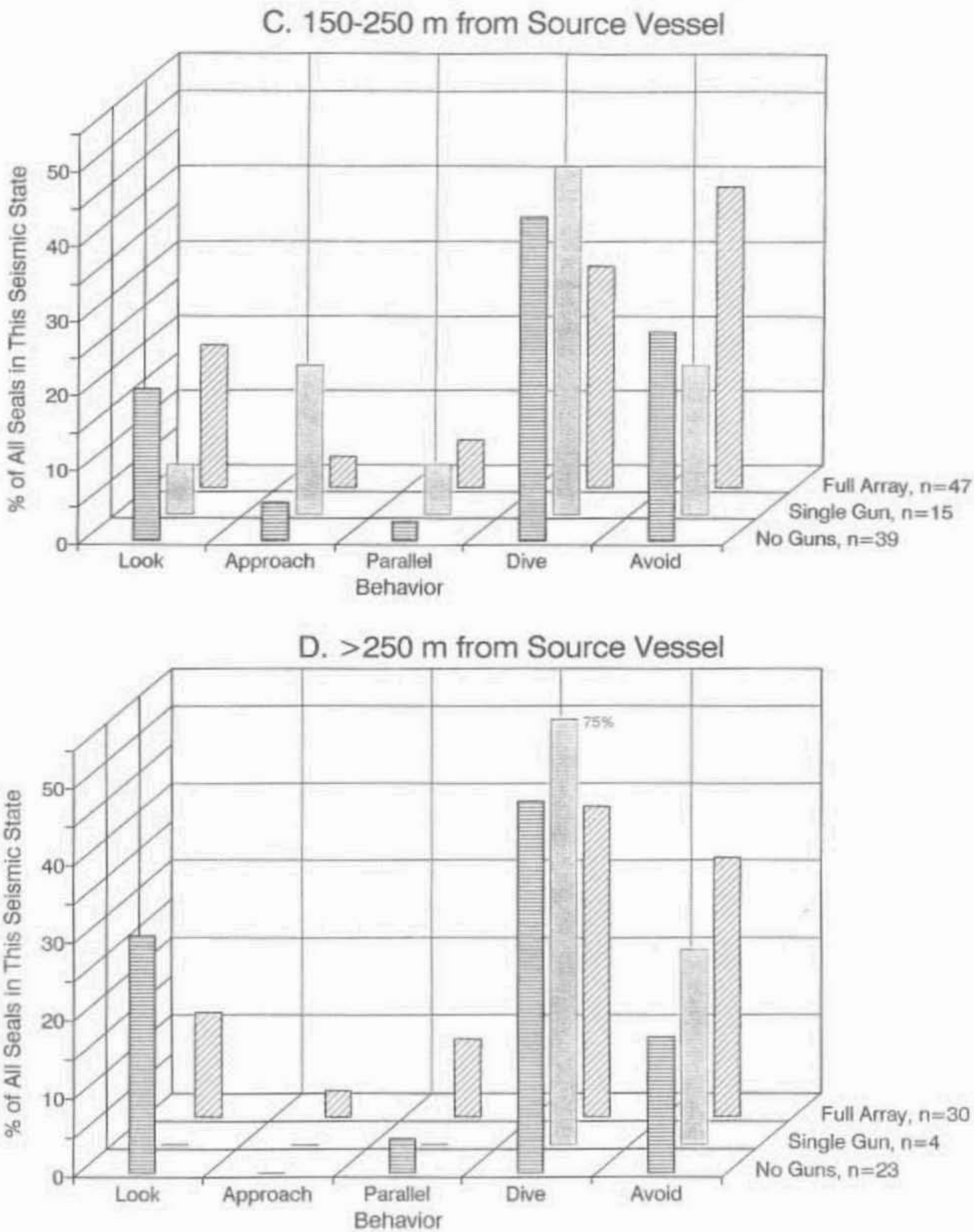

FIGURE 4.8. Continued.

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.

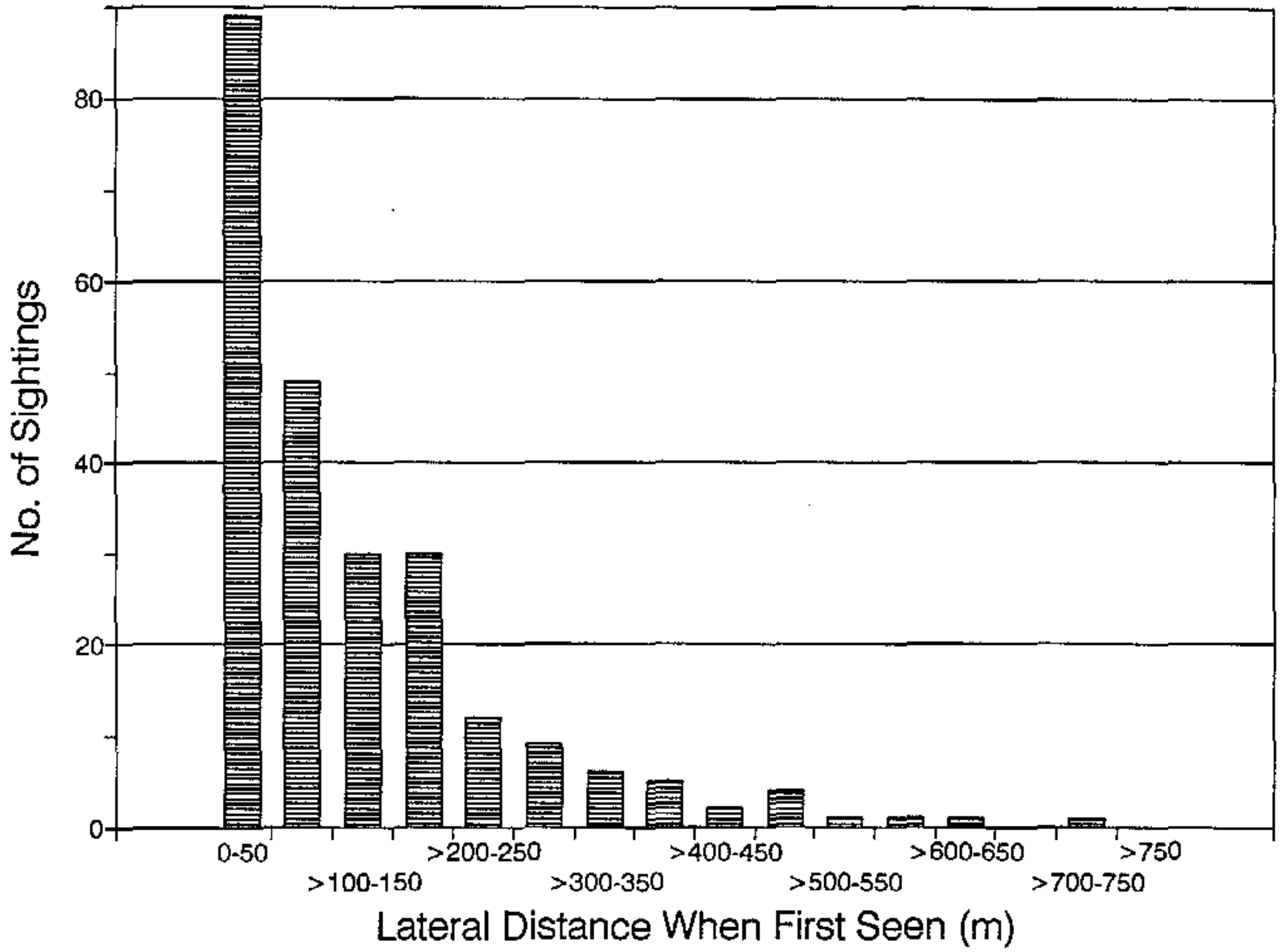

FIGURE 4.9. Numbers of seal sightings during daylight by 50 m lateral distance intervals from the source vessel's track. Lateral distance was determined from the seal's location when it was first seen.

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 air-guns 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.

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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.

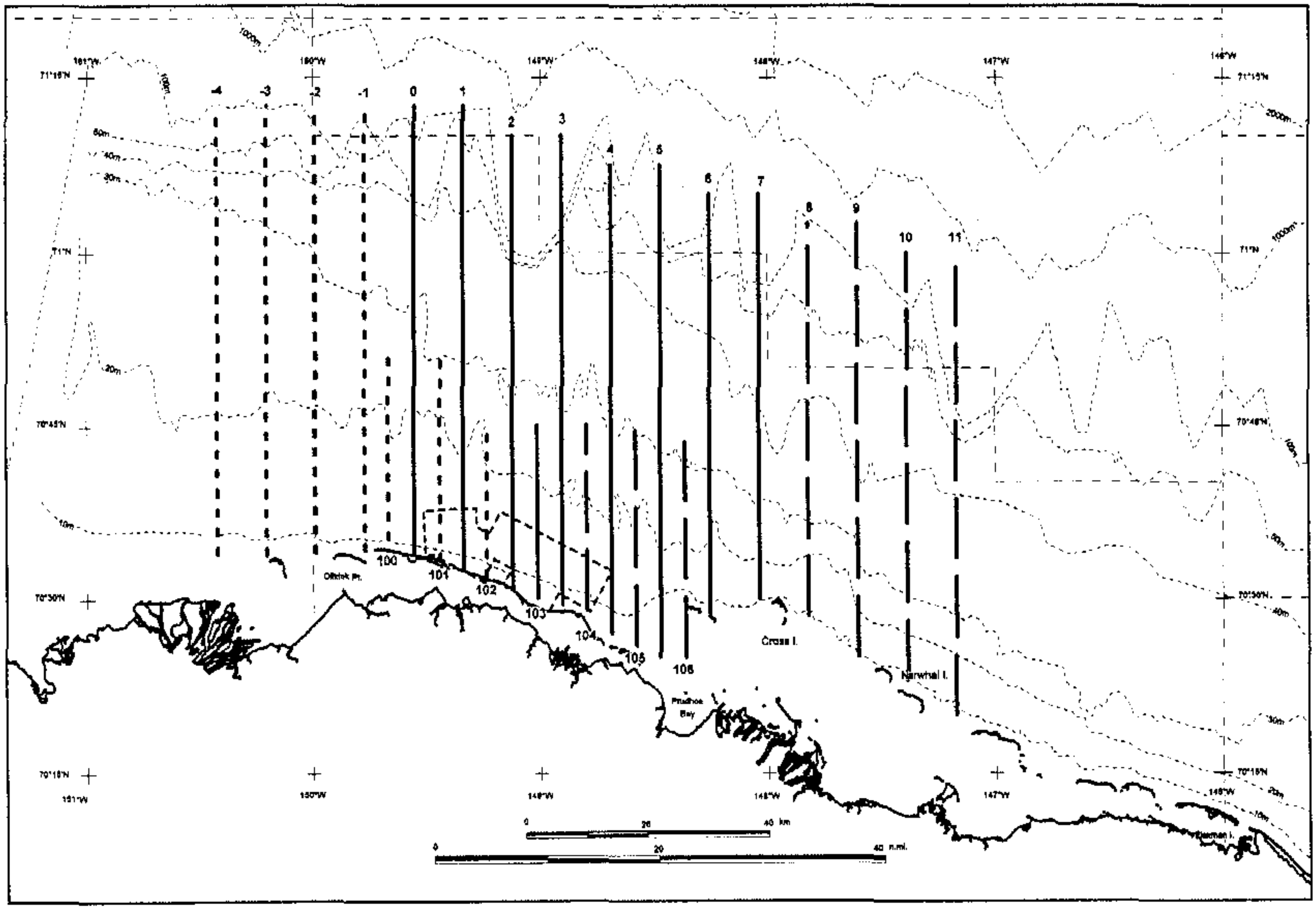

FIGURE 5.1. Standard aerial survey lines flown by LGL during September 1996 in the central Alaskan Beaufort Sea (146°-151°W). Eastern lines depicted by long dashes were part of the standard survey grids flown during the 1-12 September period. Western lines depicted by short dashes were flown starting 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

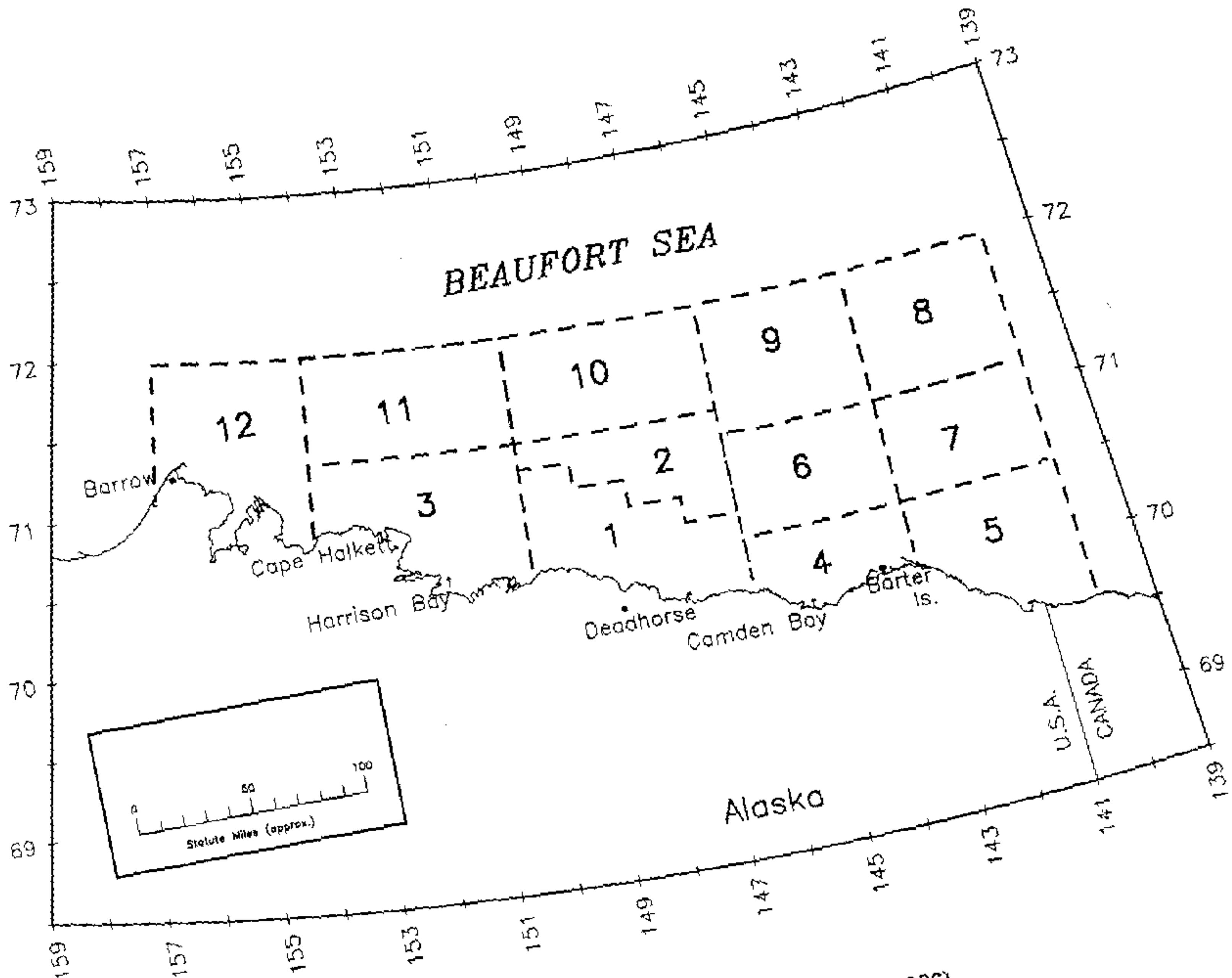

FIGURE 5.2. Alaskan Beaufort Sea, showing MMS survey blocks 1-12 (from Treacy 1996).

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

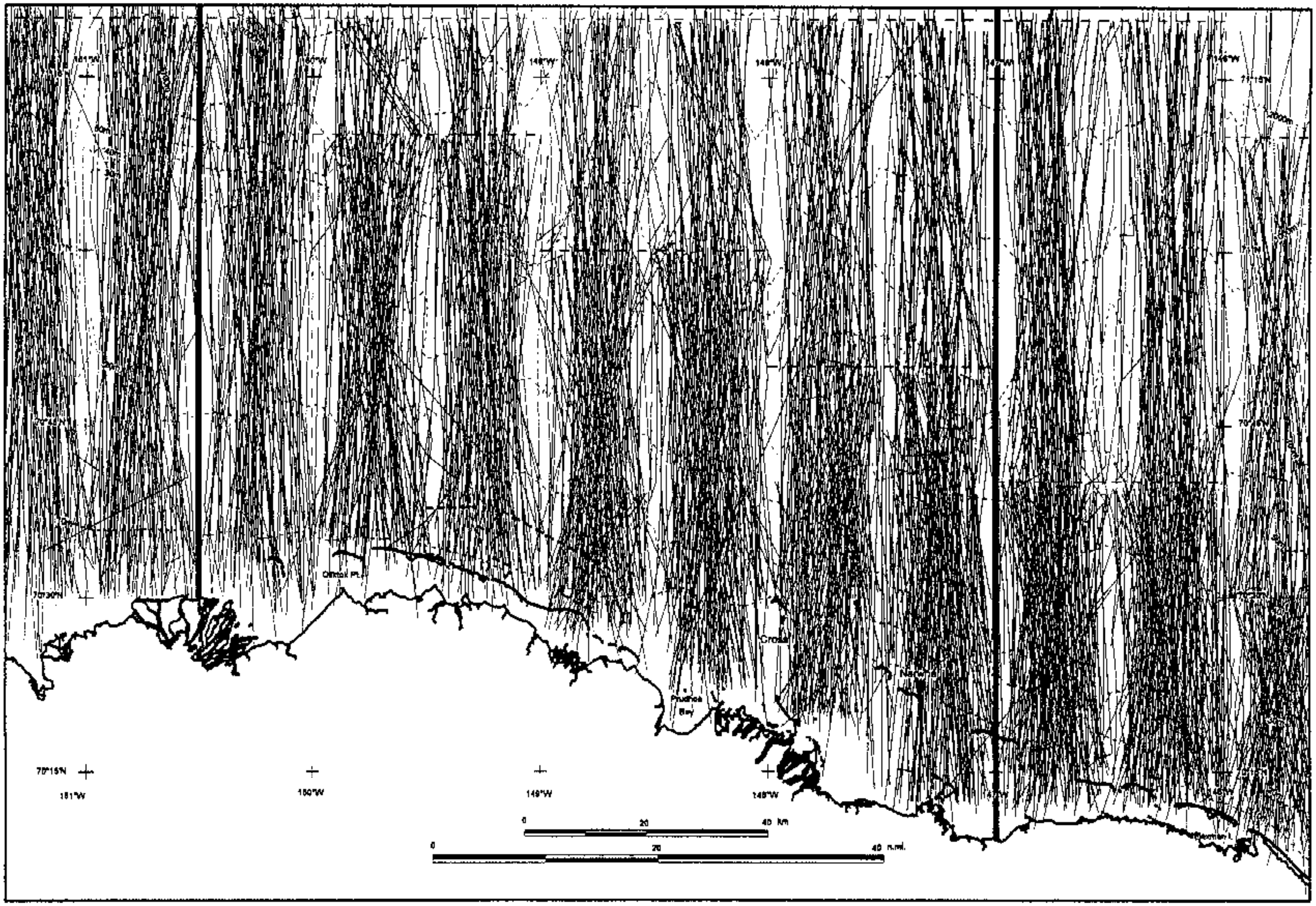

FIGURE 5.4. Aerial survey transects flown by MMS and NOSC during late summer and autumn of 1979-95 in the central Alaskan Beaufort Sea (146°-151°W). Analyses in this report were based on "Transect" sightings within the 147°-150°30'W area (bounded by solid lines). Seismic patches shot during September 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		# Days with Surveys	km of Surveys/ Day*
	First	Last		
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

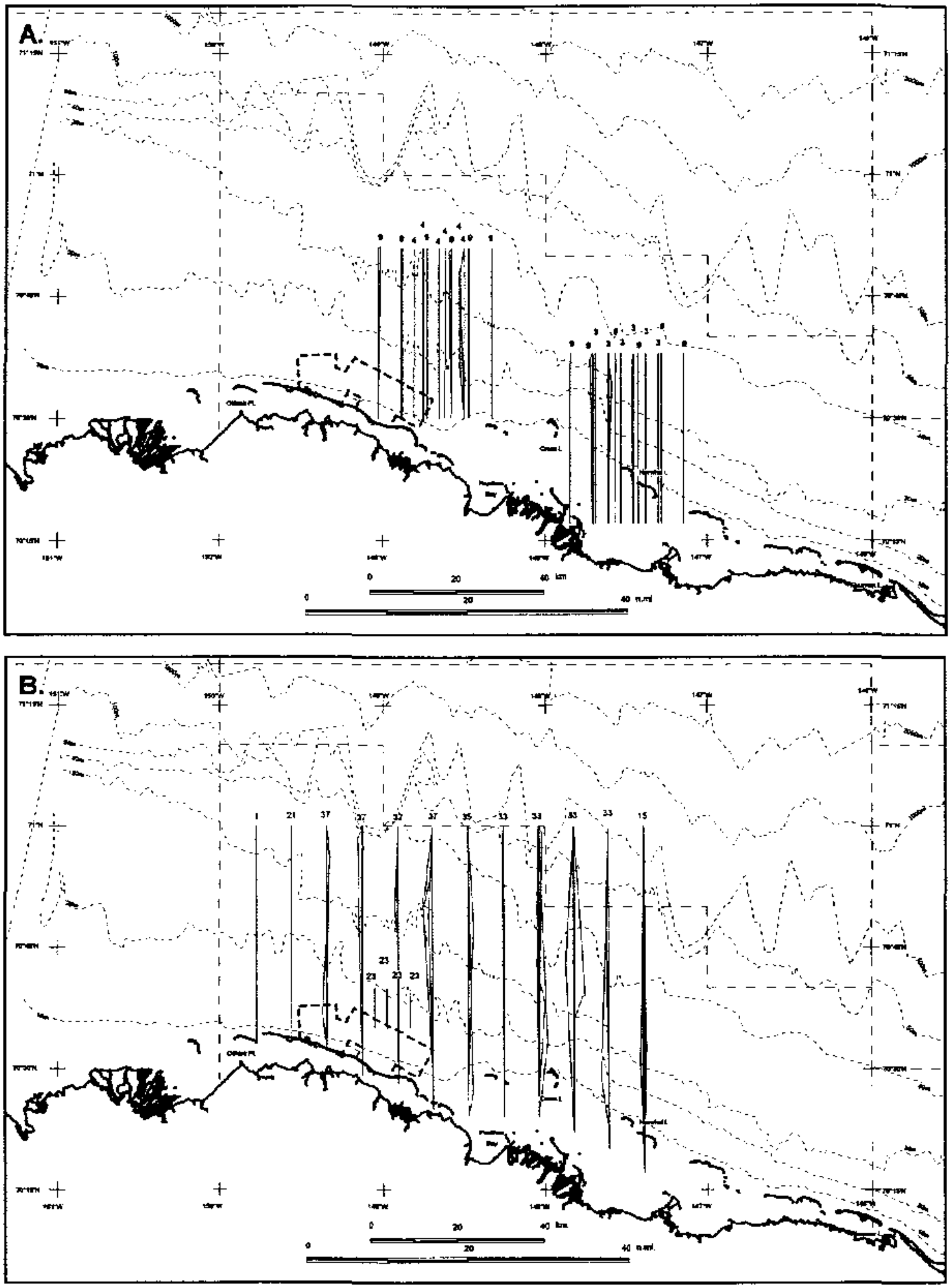

FIGURE 5.5. Aerial survey transects flown by LGL during *(A)* 1982, *(B)* 1984-85, *(C)* 1995 and *(D)* 1996 in the central Alaskan Beaufort Sea (146°-151°W). Number at the N end of each transect indicates the number of times that transect was surveyed. Analyses were based on "Transect" sightings within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

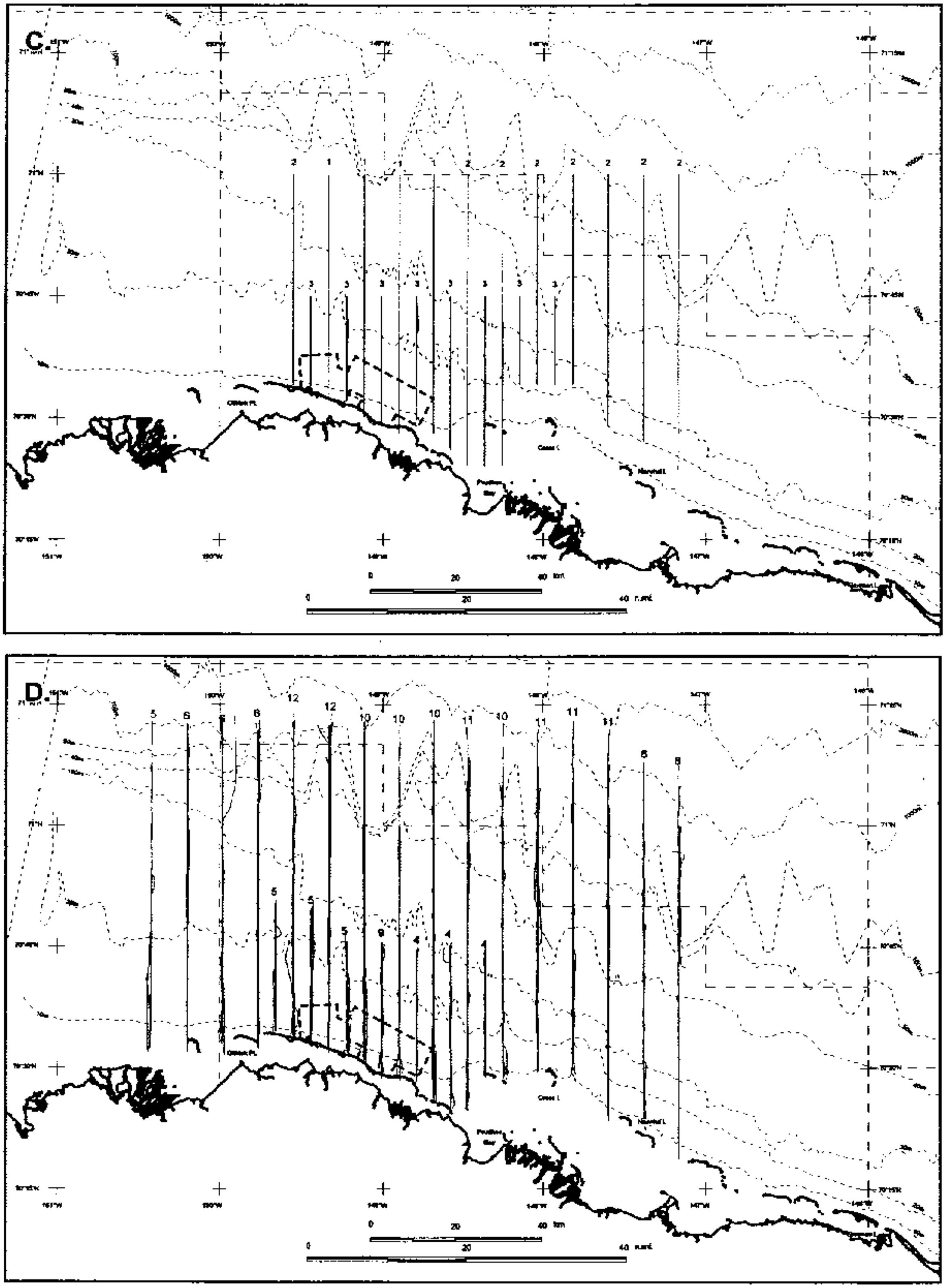

FIGURE 5.5. Concluded.

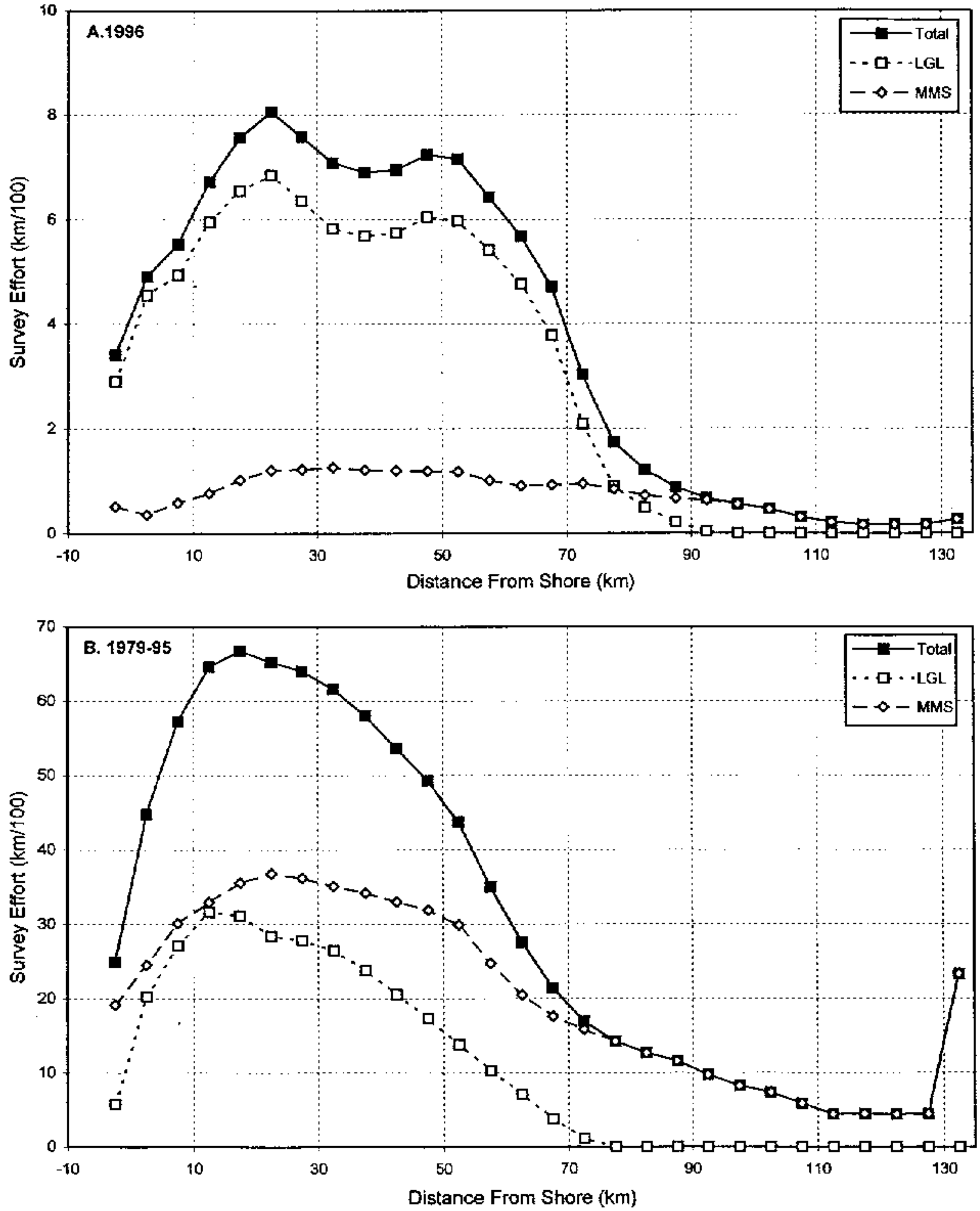

FIGURE 5.6. Kilometers of aerial survey effort at various distances from shore within the Northstar region (147°-150°30'W) during late summer and autumn, including only "Transect" surveys. *(A)* 1996. *(B)* 1979-95. Surveys with poor sightability are excluded.

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"

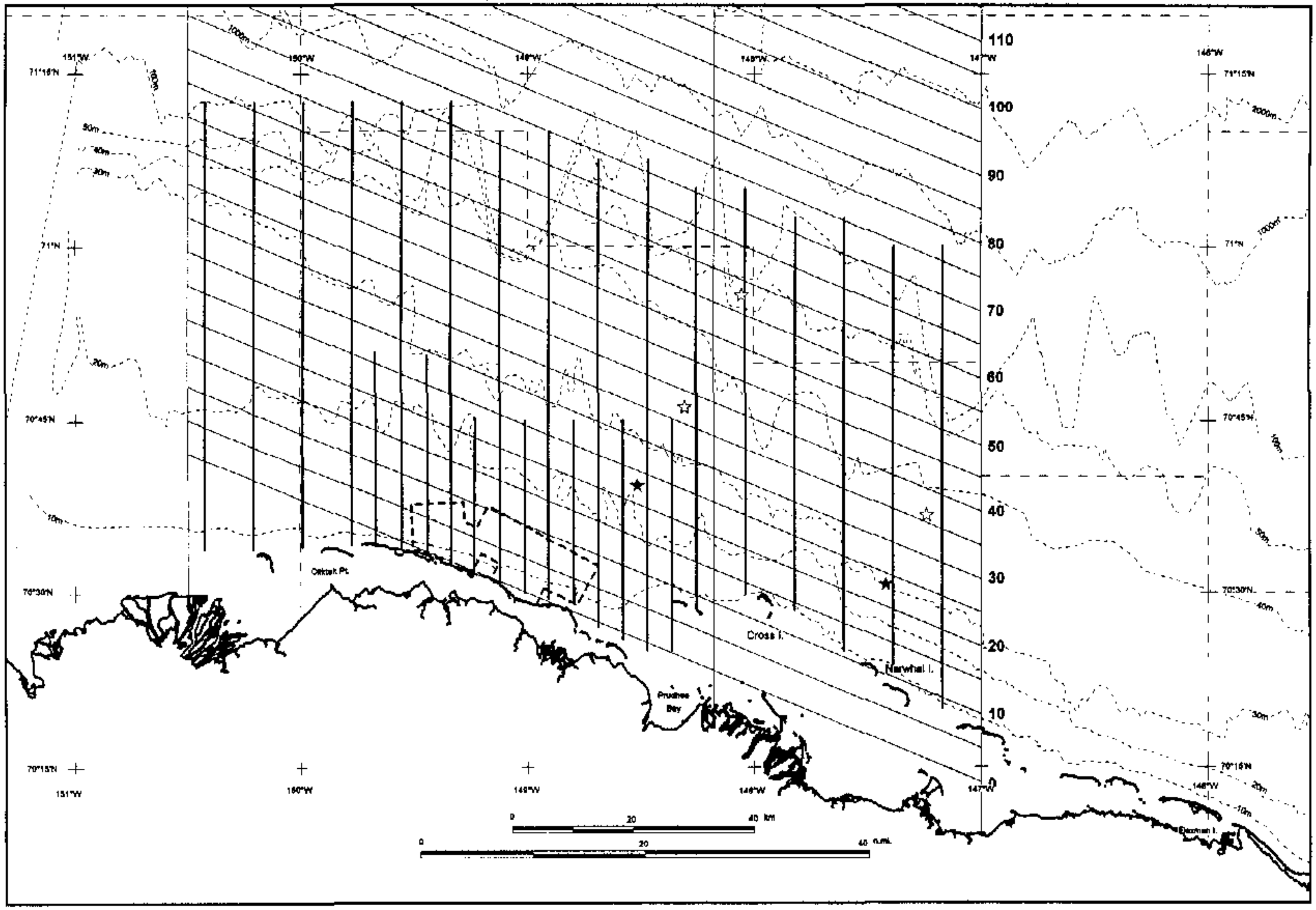

FIGURE 5.7. Categorization of the Northstar region (147°-150°30') by 5-km distance-from-shore intervals. The intervals, which continued out to 130 km offshore, were used to tabulate mammal sightings and survey effort by distance from shore. The most inshore line is defined as the "0 km offshore" line; 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.

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[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.

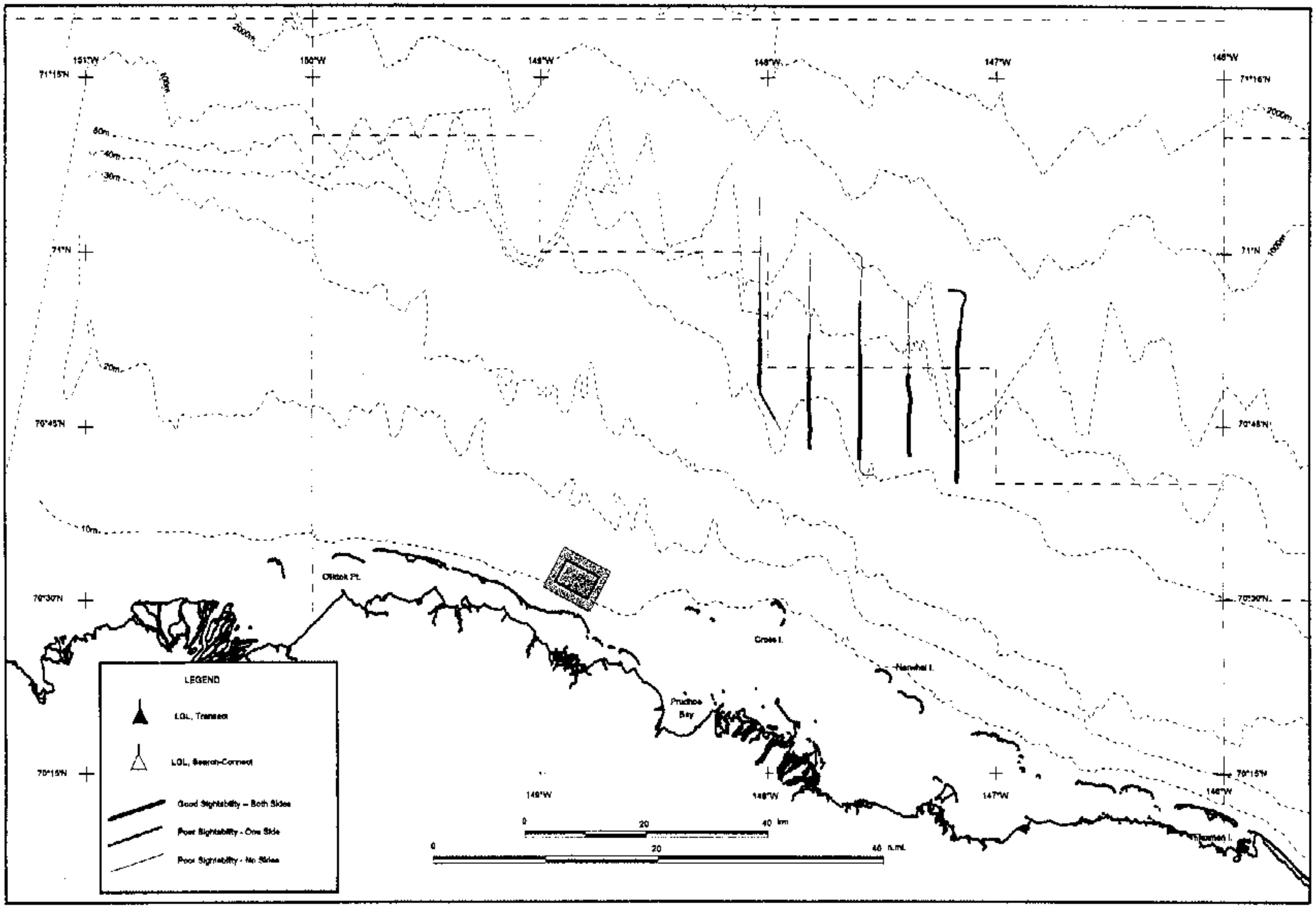

FIGURE 5.8. Aerial survey coverage of the extensive grid, 3 September 1996. Low cloud prevented surveys of much of the extensive grid and all of the intensive grid. No bowheads were sighted. The area where the source vessel was shooting full array seismic is shaded.

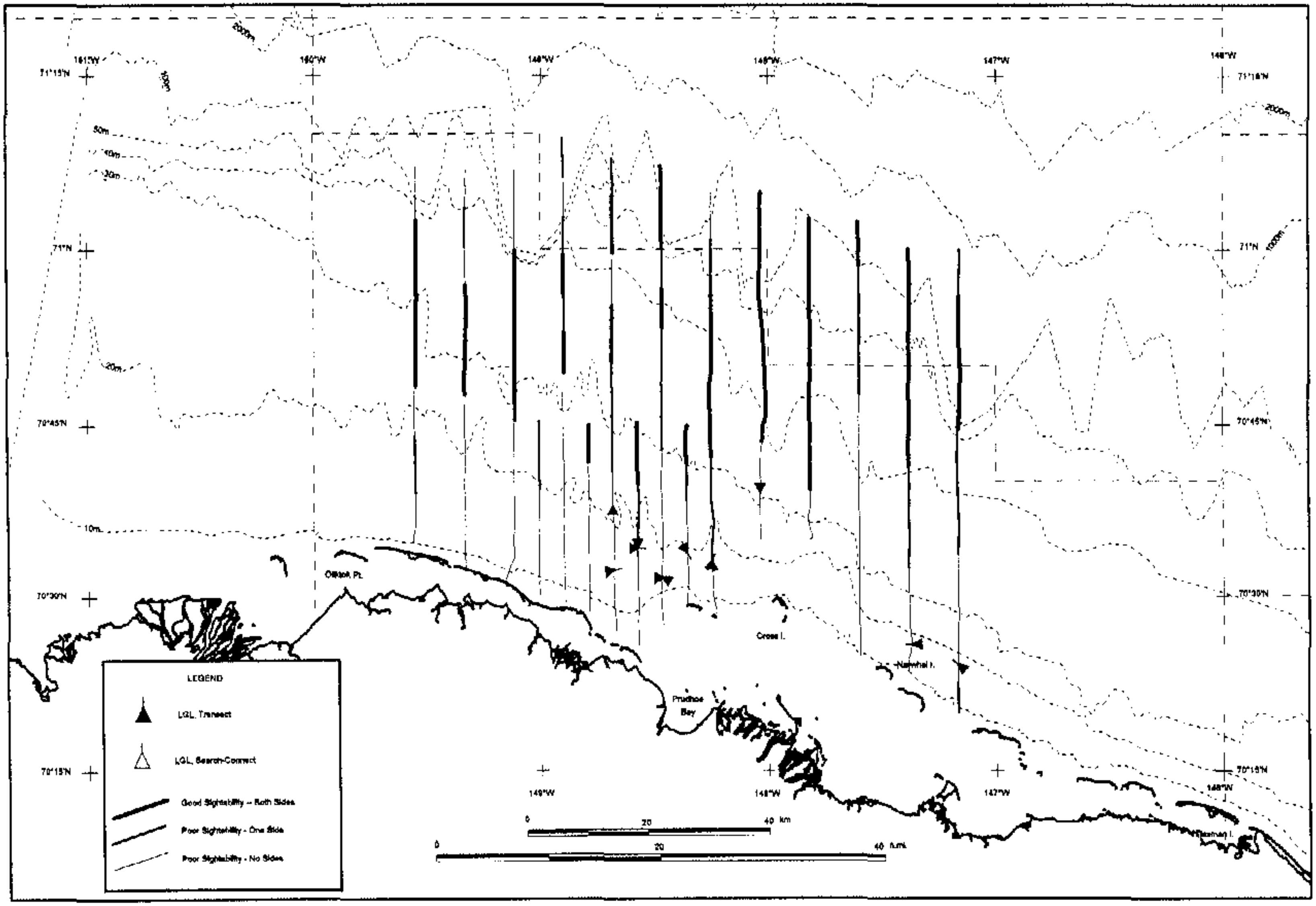

FIGURE 5.9. Aerial survey coverage of the extensive and intensive survey grids, 5 September 1996. A total of 14 bowheads were sighted. There were no airgun operations during this survey.

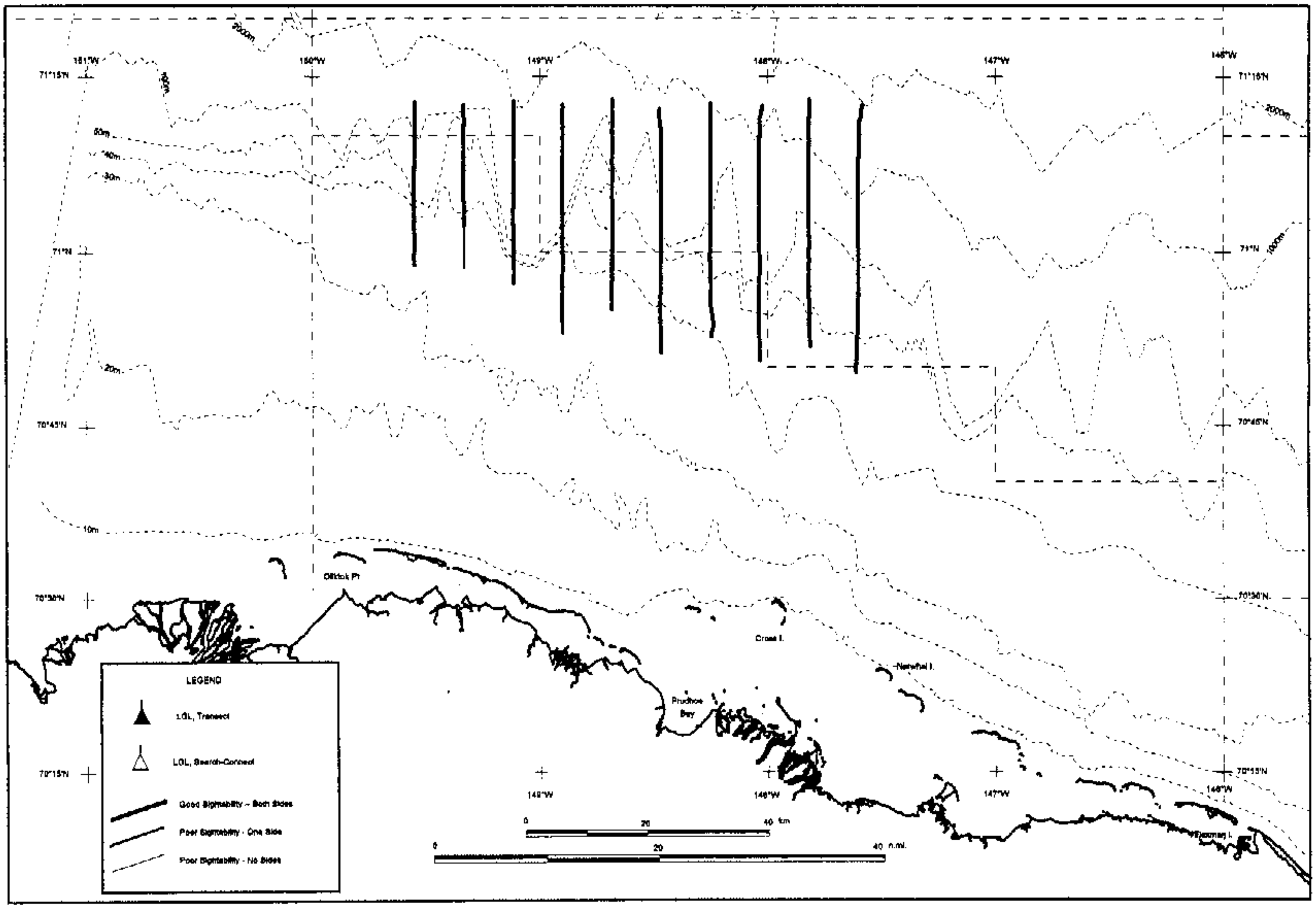

FIGURE 5.10. Aerial survey coverage of the extensive grid, 6 September 1996. Persistent fog prevented surveys of the southern part of the study area. Transects 2-9 were extended farther offshore than usual. No bowheads were sighted. There were no airgun operations during this survey.

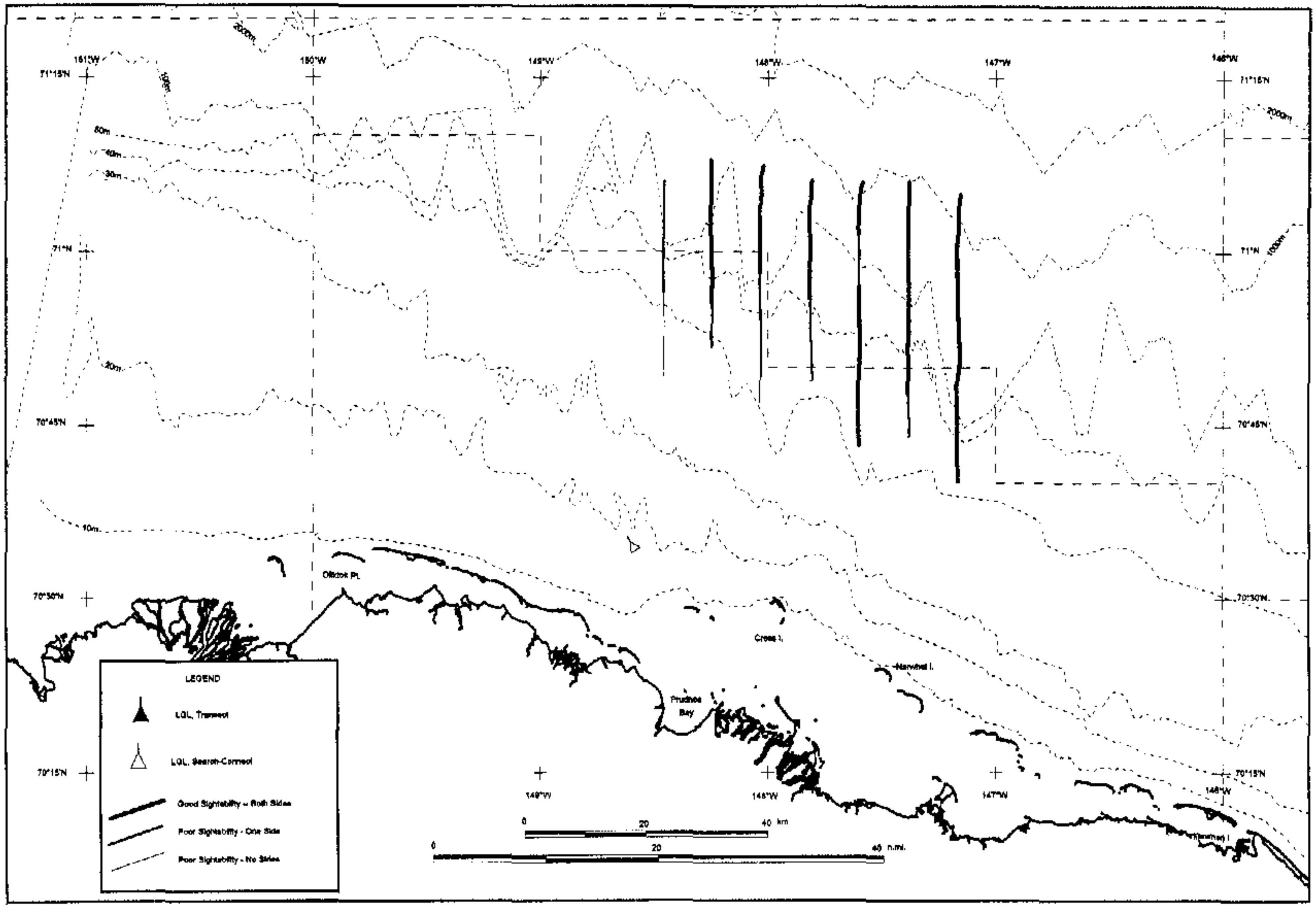

FIGURE 5.11. Aerial survey coverage of the extensive grid, 7 September 1996. Low cloud prevented surveys of much of the extensive grid and all of the intensive grid. Transects that were surveyed were extended north beyond the standard northern endpoints. Two bowheads were sighted incidentally during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

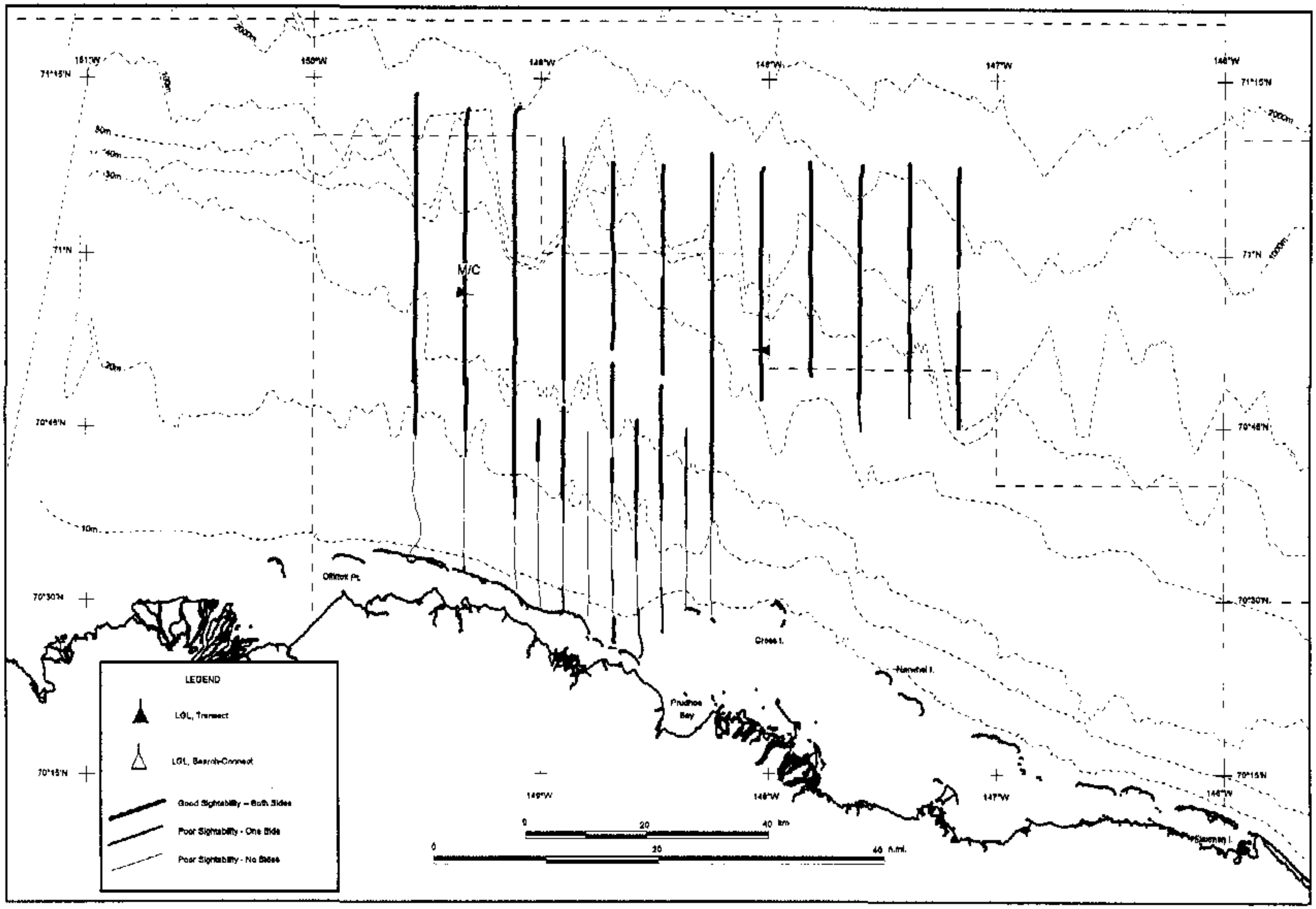

FIGURE 5.12. Aerial survey coverage of the extensive and intensive grids, 8 September 1996. Three bowheads including a mother-calf pair (M/C) were sighted. Low cloud prevented surveys of the southeastern portion of the extensive grid. There were no airgun operations during this survey.

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.

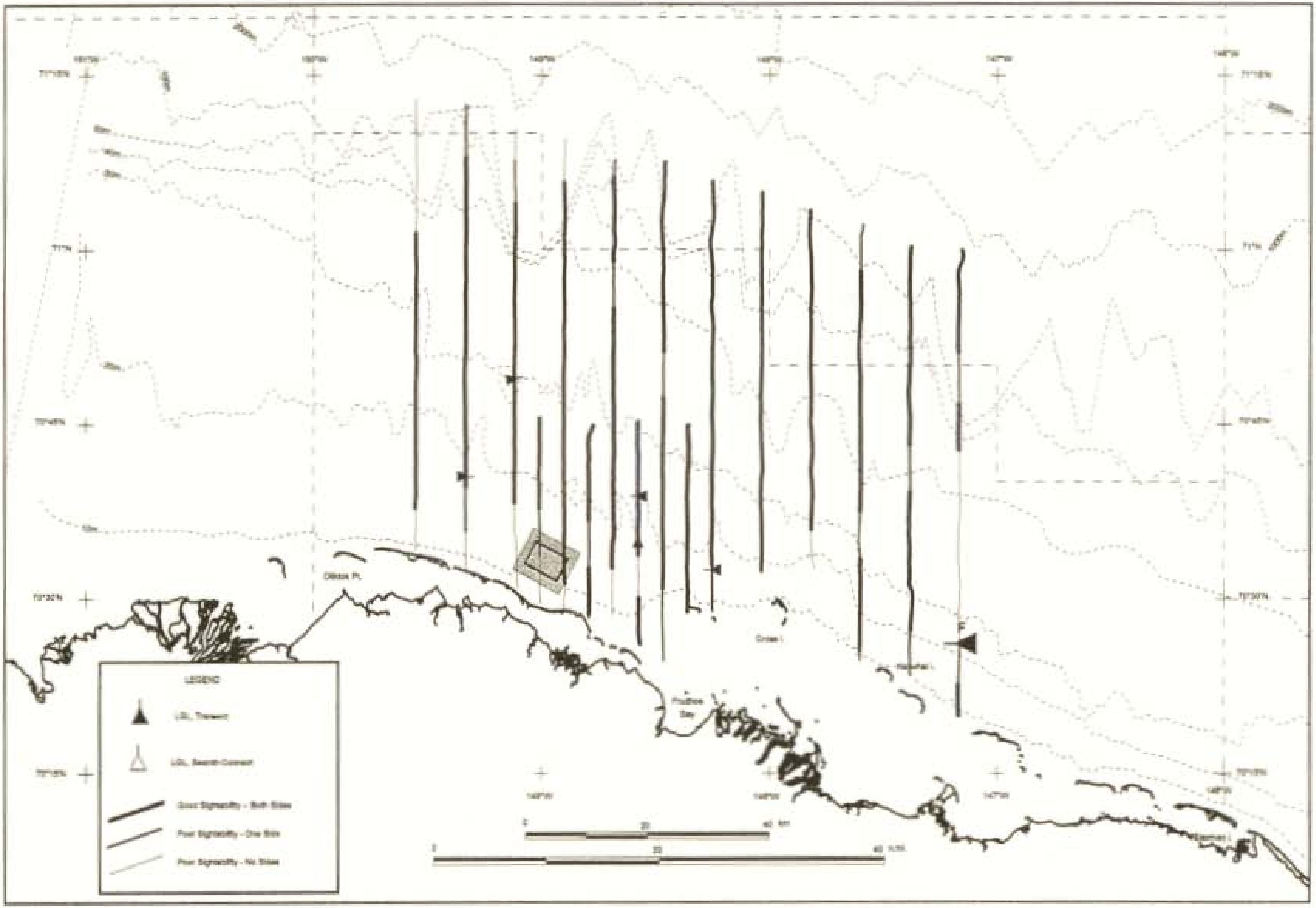

FIGURE 5.13. Aerial survey coverage of the extensive and intensive grids, 9 September 1996. Low cloud prevented surveys of the southeastern portion of the extensive grid. Seven bowheads were sighted. The large symbol with an "F" indicates the location of a bowhead sighting during full array seismic.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

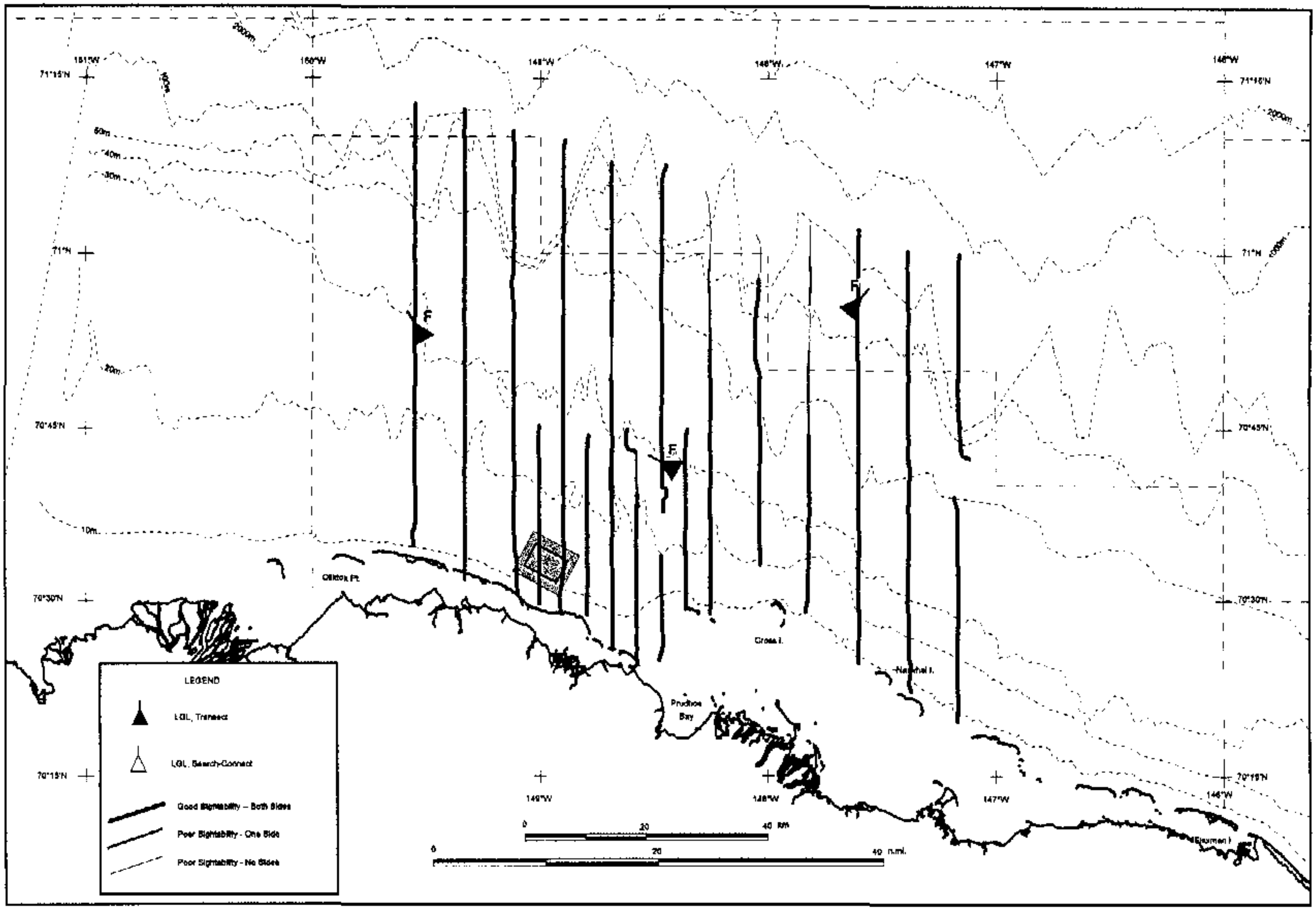

FIGURE 5.14. Aerial survey coverage of the extensive and intensive grids, 10 September 1996. Three bowheads were sighted (large symbols with an "F"). The area where the source vessel was shooting full array seismic is shaded. The southern end of survey line 7 near Cross Isl. was not surveyed in an attempt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

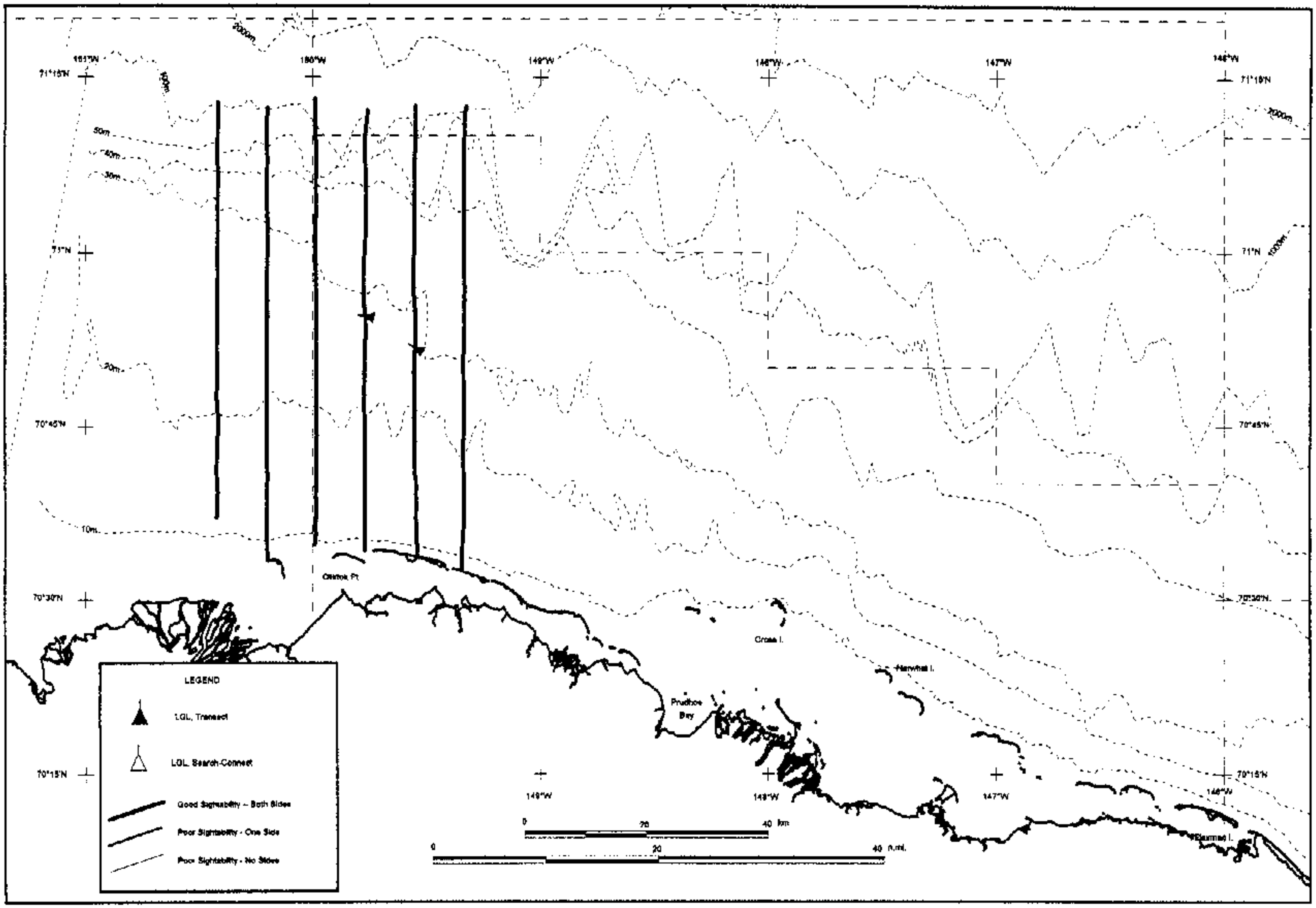

FIGURE 5.15. Aerial survey coverage of the extensive grid, 13 September 1996. The survey grid was shifted west in response to a change in the location of the seismic operations. A mis-firing aircraft engine forced an early end to the day's surveys. Two bowheads were sighted. There were no airgun operations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

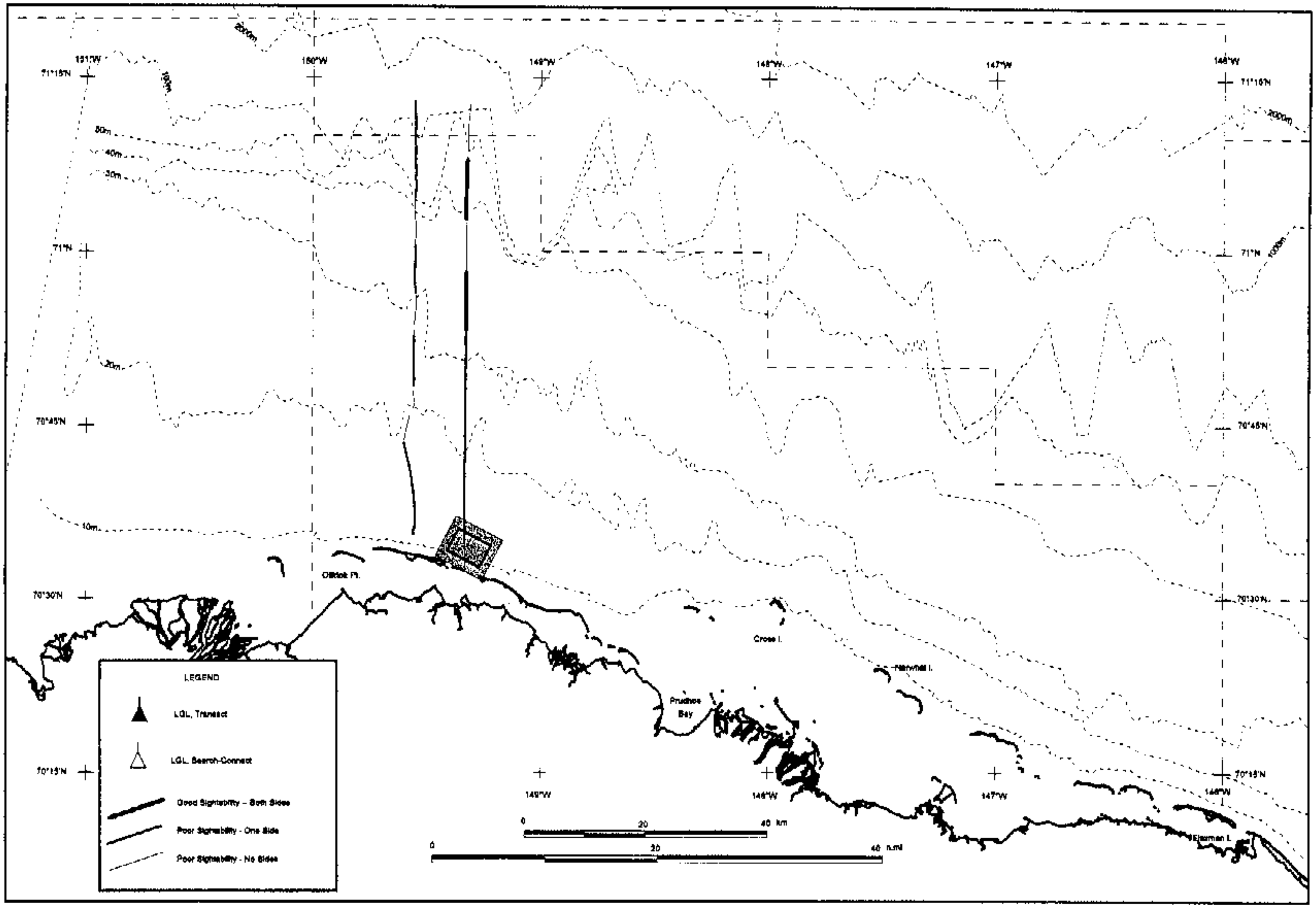

FIGURE 5.16. Aerial survey coverage of the extensive grid, 14 September 1996. Poor weather conditions, including high sea states and blowing snow, forced early termination. No bowheads were sighted. The area where the source vessel was shooting full array seismic is shaded.

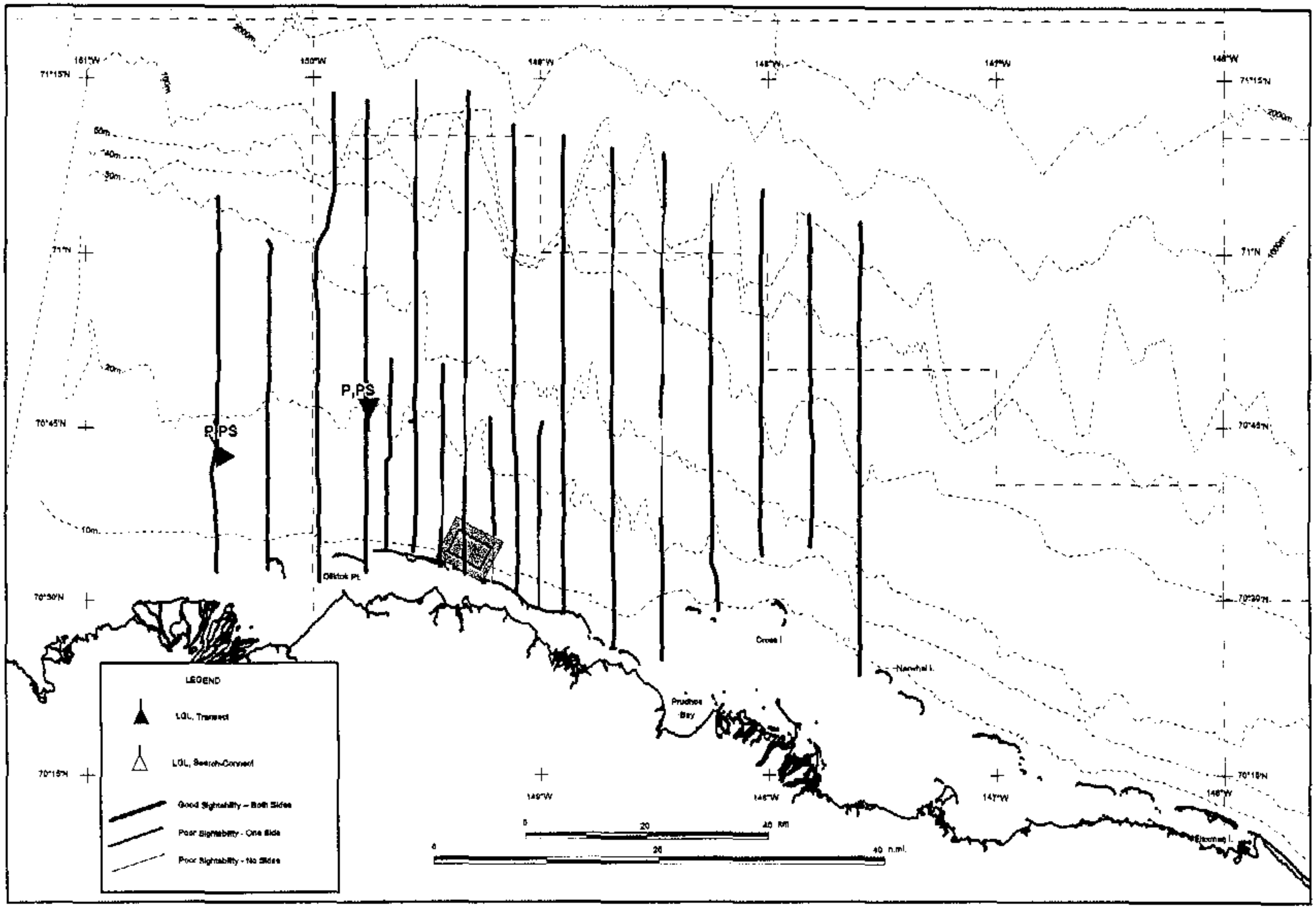

FIGURE 5.17. Aerial survey coverage of the extensive and intensive grids, 15 September 1996. Parts of some transects were obscured by snow showers. Two bowheads were sighted during partial array seismic (P) <3.5 h after a lengthy period of full array seismic (PS). The area where the source vessel was 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.

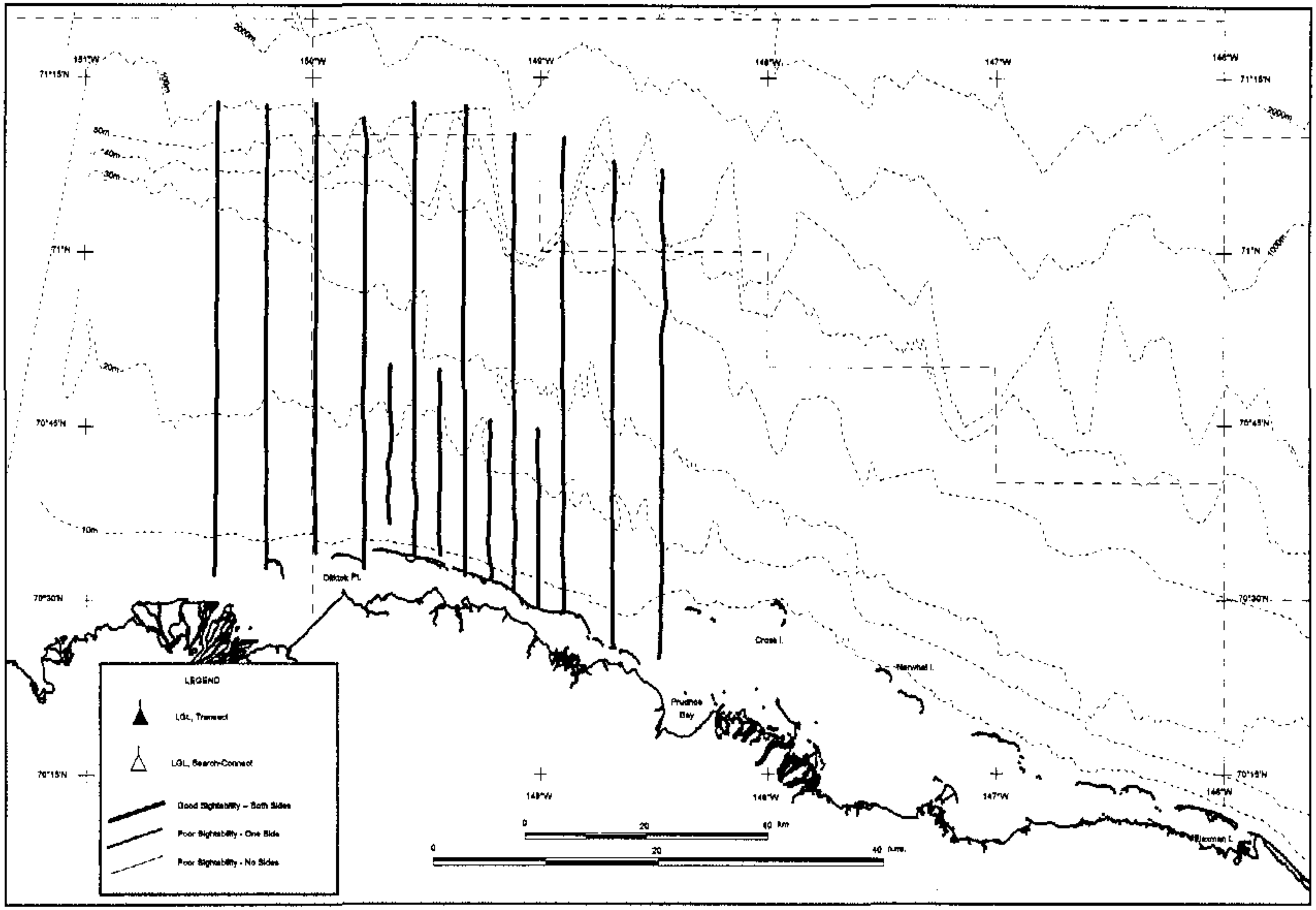

FIGURE 5.18. Aerial survey coverage of the extensive and intensive grids, 16 September 1996. Low ceilings and fog prevented surveys of the extensive grid east of transect 5. No bowheads were sighted, despite excellent sighting conditions in the areas surveyed. There were no airgun operations during this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